DELTA FISH FACILITIES PROGRAM REPORT

THROUGH JUNE 30, 1982[1/]

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1/ Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary, Technical Report No. 6. December, 1982.

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SUMMARY

The activities and accomplishments of the Delta Fish Facilities Program, from its inception to June 30, 1982, is reviewed. The report was initially prepared to support a recommendation on the fish protective facilities for the proposed Peripheral Canal. After the rejection of the project by the voters during the June, 1982 election, the report was modified to document the accomplishments, and a history of the program.

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ACKNOWLEDGMENTS

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The editors also wish to acknowledge the contributions of the Agency Coordinators, the Fish Facilities Technical Coordinating Committee, and the Fish Facilities Consulting Board. Members of these groups, present and past, and the staff of the member agencies are jointly responsible for the completion of the program.

Finally, the editors wish to remember the contributions of the late John E. Skinner, who organized and directed the program through its early years.

INTRODUCTION

The Delta Fish Facilities Study is one element of the Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Members' agencies include the California Departments of Fish and Game (DFG) and Water Resources (DWR), the U. S. Fish and Wildlife Service (USFWS), and U. S. Bureau of Reclamation (USBR). Under the direction of the Interagency Fish Facilities Technical Coordinating Committee, the Fish Facilities Study was charged with the task of developing engineering and biological design criteria, recommending the design, and providing operation and maintenance requirements for the fish protective facilities of the proposed Peripheral Canal. This report is being prepared to briefly review the history of the Fish Facilities Program, review the applicable engineering and biological literature on the system, summarize the progress of studies to date, present and support the preliminary design criteria, and set the foundation for the initial facility recommendation. This report was prepared prior to the rejection of the project by the voters on June 1, 1982. While the project will not be built, most of the study results have wide applicability to fish screen design and are particularly pertinent to any diversion from the Sacramento River. Hence the report still has considerable value.

The Peripheral Canal would have been an isolated conveyance facility which would have diverted water from the Sacramento River about 25 km (16 mi) south of Sacramento, California and convey it around the eastern periphery of the Sacramento-San Joaquin Estuary (Delta) to the existing State and Federal pumps and canals in the southern Delta (Figure 1). The initial reach of the canal would have had a capacity of 617 m^3 sec^{-1} (21,800 ft^3 sec^{-1}). The intake was to have been screened with a "low velocity-positive barrier" which would have allowed the fish that were screened to continue along their normal migration route without handling. The release of water for water quality purposes may present a fish attraction problem, but of a smaller magnitude than exists with the present system.

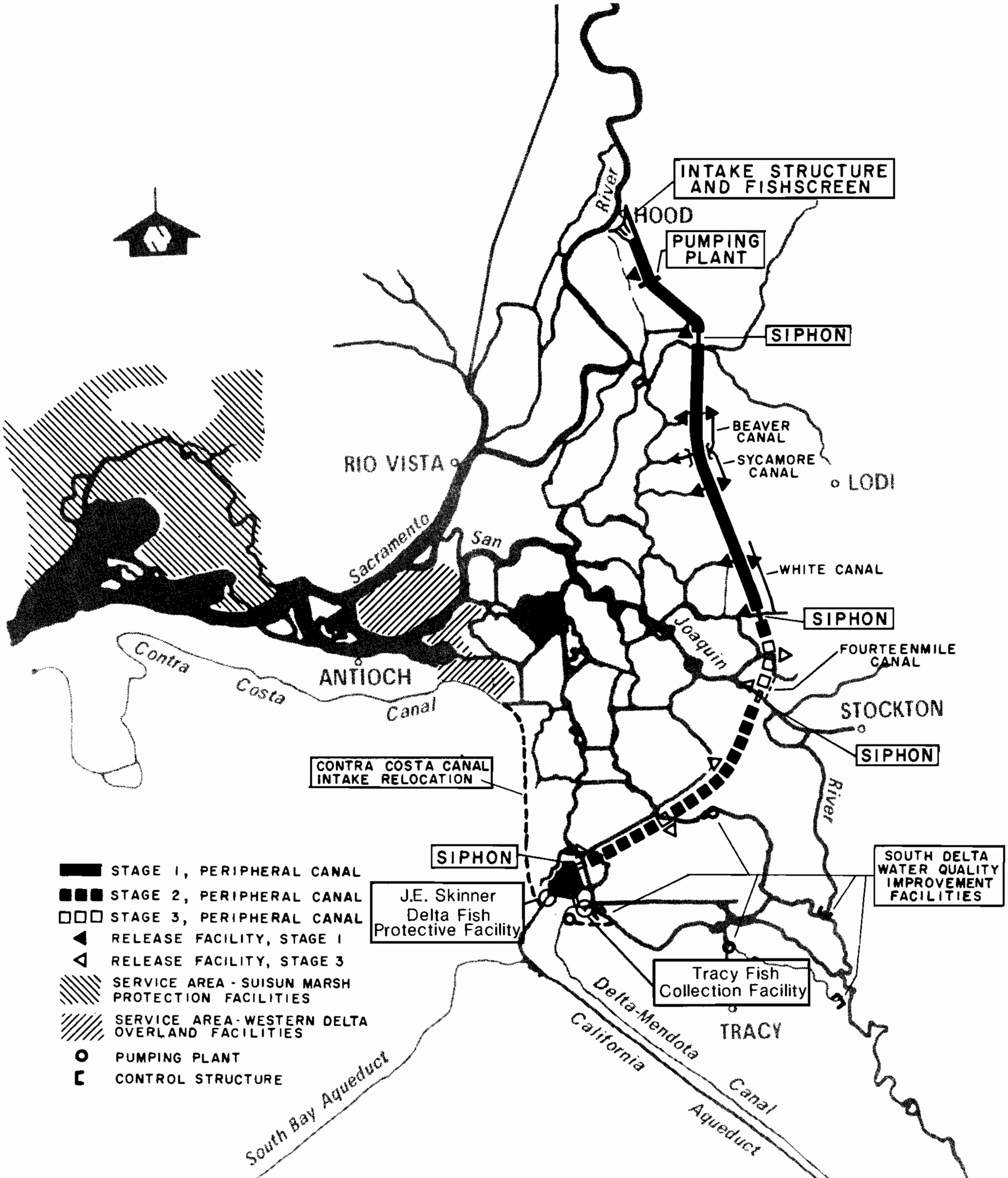
Program Description

Work on fish screens in California goes back to the early 1900's, with numerous ideas tested and hundreds of fish screens installed throughout the state. Early work was conducted by the DFG, primarily in the upstream nursery areas for salmonids.

The earliest work on the problems associated with fish facilities to protect the aquatic resources of the Delta can be traced back to the late 1940's, when biologists working for DFG and USFWS developed the louver fish screen concept, which was used at the intake of the Central Valley Project (CVP) (Bates and Vinsonhaler 1956). This was closely followed by the work for the Pacific Gas and Electric (PG&E) Contra Costa steam plant which began in 1950 (Kerr 1953). When the State of California began planning the

FIGURE 1

PERIPHERAL CANAL AND ASSOCIATED FACILITIES



State Water Project (SWP) in the 1950's, a physical barrier was proposed to provide yield and protect water quality in the Delta and export waters by blocking intrusion of ocean salts. The most feasible barrier alternative was called the Chipps Island barrier, and in 1956 experiments were conducted to determine if a vertical baffle fishway would be suitable to pass striped bass, Morone saxatilis, American shad, Alosa sapidissima, and sturgeon, Acipenser spp. (Fisk 1959).

The State continued work on the SWP, and in 1960 gained voter approval to construct the SWP facilities. The Delta Fish and Wildlife Protection Study (a joint effort by DFG and DWR) began formal operations in July, 1961 and early fish facility studies were aimed at resolving problems associated with the various barrier plans. During 1962, the Peripheral Canal was proposed by the USBR as an alternative to the projects under consideration which at that time included several physical barrier plans, and the Hydraulic Barrier Plan (Delta Fish and Wildlife Protection Study 1963). The Peripheral Canal was selected for consideration by the Interagency Delta Committee whose members included representatives of the USBR, U. S. Army Corps of Engineers, and DWR. By 1964, evaluations of the four engineering plans for transporting water across the Delta conducted by the Delta Fish and Wildlife Protection Study staff identified the Peripheral Canal as the most desirable, followed by the Waterway Control Plan and the Hydraulic Barrier, while the physical barriers were the least desirable (Delta Fish and Wildlife Protection Study 1964). The Peripheral Canal was officially adopted as a feature of the SWP in 1966, and in 1969 the Peripheral Canal was recommended as an additional feature of the CVP in a feasibility report prepared by the USBR. Subsequently the State issued a Draft Environmental Impact Report on the Peripheral Canal in 1974, and the Federal government prepared a working draft of their Peripheral Canal Draft Environmental Impact Statement in 1977.

The first phase of the SWP included a diversion point in the south Delta, similar to the intake of the CVP Delta-Mendota Canal. The Fish Facilities Program conducted evaluations of the CVP Tracy Fish Collection Facility, and made design recommendations for a louver fish screen at the intake of the SWP California Aqueduct. The early studies were designed to establish louver slat spacing, bypass design criteria, means of achieving precise velocity control in the channels, and means of reducing head loss through the facility. The result was a louver facility which represented the state-of-the-art in fish screening for large volumes of water. The provision of a fish screen in the south Delta was considered a temporary solution, and concurrent work on new screening systems including a sonic guidance device and a horizontal traveling fish screen was carried out. Tests on pumps to return the salvaged fish to the river were conducted, followed by swimming ability tests for juvenile fish. Much of the work described above was summarized in a memorandum report on the Peripheral Canal fish facilities (California Departments of Fish and Game and Water Resources 1971).

The Delta Fish and Wildlife Protection Study was replaced by the Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary in July, 1971. The revised program included for the first time the USFWS and USBR as formal participants. Technical committees were formed to provide study coordination, and the National Marine Fisheries Service was invited to participate in the activities of the Fish Facilities Technical Coordinating Committee.

The Fish Facilities Program continued with an evaluation of the new SWP Fish Protective Facility, which resulted in a set of operating criteria for the facility. The low efficiency of louver fish screens for small fish, documented for the SWP and CVP screens, lead to a decision to abandon louvers for the Peripheral Canal. A "low velocity-positive barrier" concept was adopted instead. The original concept of an "in-canal" location for the fish screen, several miles from the point of diversion, and below the sediment basin was also rejected because of predation problems associated with such a structure ahead of the fish screens, and problems involved in returning fish to the river.

During the early 1970's, several screening concepts were reviewed and either rejected or retained as candidates for the Peripheral Canal intake. Also, a decision was reached to protect eggs and larvae with a curtailment of diversions rather than screening. This decision was based on the lack of any technology to screen eggs and larvae in a diversion of several thousand cubic feet per second. The above decisions are significant because they have guided the course of the studies since that time, and were summarized in a report prepared and transmitted to all participants on August 2, 1974 (Skinner 1974).

The staff decisions summarized by Skinner (1974) were accepted by the Directors of the agencies in early 1974, and a recommendation to proceed with a "low velocity-positive barrier" located "at-river" was adopted. The Directors also decided to form a Fish Facilities Consulting Board to provide for independent review of the program direction and conclusions.

Fish Facilities Consulting Board

A Fish Facilities Consulting Board was created in 1974 and was initially composed of Dr. Loren Jensen, Chairman; Dr. James Harder, Vice-Chairman; Dr. Ernest Salo; and Mr. Milo Bell. The Board expanded in 1979 with the addition of Mr. Don Kelley, and again in 1981 with the addition of Mr. Charles Wagner. These individuals bring a broad base of experience in both the design and construction of fish facilities and the biological effectiveness of the facilities constructed to date. They have met with staff on a regular basis to review findings and program direction and to advise the Agency Coordinators on the progress and future direction of the studies.

Staged Construction

The legislation authorizing the construction of the Peripheral Canal (SB 200, enacted in late 1980) called for the project construction to be staged. One of the requirements, which directly affected the Fish Facilities Program, was to build a portion of the fish screen and conduct an evaluation of its effectiveness prior to completing the Canal. As planned, the Canal would have been built in three stages (Figure 1). Stage 1 would have consisted of the Canal from the Sacramento River to Shima Tract, and approximately one-quarter of the intake and fish facilities. Water diverted would have been released back into Delta channels at several points and re-diverted by existing project intakes in the southern Delta. Stage 2 would have consisted of pre-consolidation of the soil for the reach from the San Joaquin River to Clifton Court Forebay. Stage 3 would have begun after the evaluations had shown the fish screens to adequately protect fish populations and would have consisted of the remainder of the fish screens and completion of the reach from Shima Tract to Clifton Court Forebay.

The staging requirement presented a number of problems to the design of the facility. One problem was the practicality of building and operating a portion of the facility without making an irretrievable commitment to the design of the remainder of the screen. Another was designing the facility in a manner which met the biological design criteria, allowed meaningful testing of the facility, and provided a realistic basis for applying the results to a decision on the remainder of the facility.

Fish Screening Concept Review

The program staff has reviewed the feasibility of many screening concepts, and has conducted laboratory and field evaluations of the more promising concepts. The conclusions reached here are specific to the Peripheral Canal intake and should not be taken as a blanket endorsement or condemnation of a specific concept.

For the purposes of this report we have separated the various screening concepts into two major groupings. The first, Behavioral Devices, includes a number of screening concepts which create a stimulus causing the fish to react and avoid the screen. The second group, Positive Barriers, presents a barrier to fish passage but may generate secondary stimuli which guide the fish past the diversion. The divisions are arbitrary in that some behavioral devices may serve as positive barriers for larger fish while positive barriers do not necessarily exclude all sizes of fish due to the size of the openings in the screening material.

Behavioral Devices

Behavioral devices depend on creating one or more stimuli which cause fish to react in a desired and predictable manner, avoiding the diversion. This response depends on the fishes' capability to detect the stimuli, and the fishes' ability to react in the desired manner and avoid the diversion. Both of these factors are affected by the species of fish in question and the size of the fish. Different species develop their vision and lateral line sense at different stages and within a species the development of both sense and swimming ability is size specific.

Louvers - Louver screens consist of a series of slats, oriented vertically, which create a turbulence in the water. The louver array crosses the channel at a shallow angle and utilizes the turbulence to guide the fish to a bypass (Figure 2).

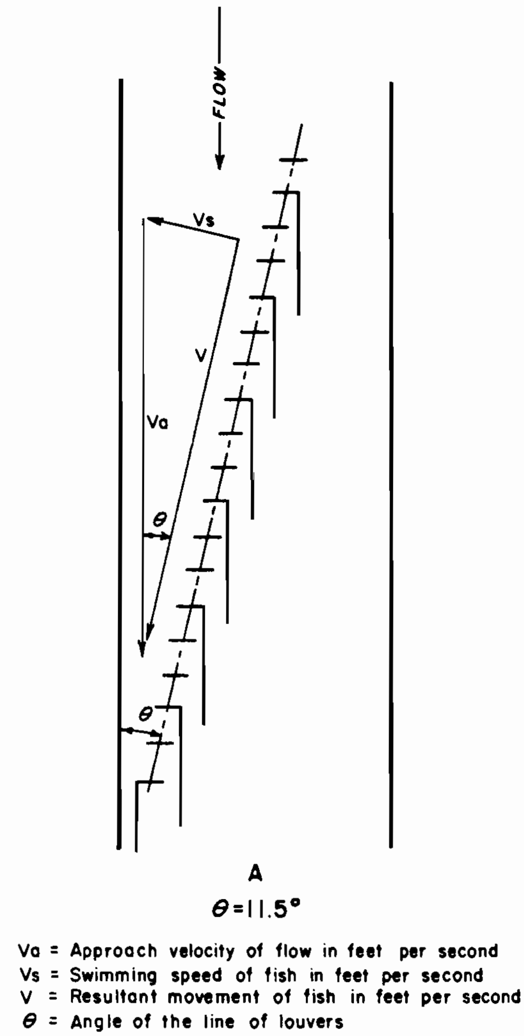


FIGURE 2. Diagram showing angle of louvers and vectors of force in flow and fish movement (From Skinner, 1974b)

Louvers were developed by DFG and USFWS for the Tracy Fish Collection Facility at the intake to the Delta-Mendota Canal, a feature of the CVP, located near Tracy, California. The earliest published report on the development of the louver screen was prepared by Bates and Vinsonhaler (1956). Since that time, numerous efforts have been made to evaluate and improve the concept. Hallock, Iselin, and Fry (1968) conducted an independent evaluation of the Tracy Facility. Other workers who attempted to perfect the system include Ruggles and Ryan (1964) who evaluated the potential of louvers for guiding juvenile salmonids, Thomson and Paulik (1967) who tested louvers at Mayfield Dam in Washington, and Meinz (1978a) who evaluated factors affecting louver guidance efficiency for juvenile chinook salmon (Oncorhynchus tshawytscha). These studies all showed that louvers functioned effectively to screen fish large enough to detect and avoid the louvers.

The hydraulic factors relating to louvers are fully described in a report by the Hydraulics Research Station, Ministry of Technology, Wallingford, Berkshire, England (1967).

A second major louver installation became operational in 1968 at the intake of the SWP California Aqueduct, located near Byron, California. A two-year evaluation of this State facility was completed in 1972 (California Departments of Water Resources and Fish and Game 1973).

The evaluation of the State facility and subsequent office evaluation of the Federal facility, which was completed in 1973 (Heubach and Skinner 1978), led to a series of conclusions on the applicability of the louver screen for the Peripheral Canal. The rejection of this screen concept was based primarily on studies demonstrating that louvers are not efficient devices for screening fish less than 38 mm (1.5 in.) in length, since efficiencies were generally less than 50% for these small fish.

Sound - Various frequencies, intensities, and patterns of sound have been tested in an attempt to attract or repel fish. Moore and Newman (1956) found no effect on coho salmon (Oncorhynchus kisutch) of sounds between 5 and 20,000 cycles per second, other than an initial "startle" reaction to a new sound. Burner and Moore (1962) found similar results for rainbow trout (Salmo gairdneri) even at extremely high intensities. Attempts to frighten fish from power plant intakes have also been unsuccessful (Schuler 1974; Schuler and Larson 1974). Fish generally become rapidly accustomed to sound, making sound ineffective for guidance. Stahl (1975) reviewed the literature relating to sound and its effects on fish.

Preliminary tests conducted by the program staff in 1963 and 1964 showed some success with sound guidance for chinook salmon but low success for striped bass (Painter, unpublished data). A large sound guidance test facility was built near Tracy and tested without success. The failure of this large system led to a decision to abandon sound as a screening technique for this program.

Electricity - Guidance and repulsion of fish with electrical fields has been tested in a wide variety of conditions and on many sizes and species of fish (Applegate, Macy, and Harris 1954). Efforts to screen fish by this method have diminished in recent years, mainly because of the size selective nature of electricity. Different pulse widths and voltages are required to stimulate different sizes and species of fish. A system set up to guide small fish may well be lethal to larger fish. Maxwell (1973) contains a comprehensive review of electrical screens and concludes that they are not reliable enough for large scale applications. No subsequent work has changed this conclusion.

Air Bubbles - Bubble screens or curtains have been used at several power plant intake sites to repel fish. Some success has been attained with strongly schooling fish (alewives, *Alosa pseudoharengus*) but results were less encouraging for solitary fish (striped bass and white perch, *Morone americana*) (U. S. Environmental Protection Agency 1976). Work on salmon in the Pacific Northwest showed bubble screens to be ineffective (Bell 1973). Subsequently, Lieberman and Muessig (1978) reported that air bubbles were ineffective as a deterrent for fish on the Hudson River. These failures led to a decision to reject this concept for our program.

Light - Light may either attract or repel fish, depending on the type and intensity of light, the size and species of fish involved, and the time of day or night. Light was tested as a means of guiding salmon (Johnson, Fields, Harekar, and Finger 1958), but variable results were obtained.

Recent work (Patrick MS) showed that in clear water, strobelights could be used to repel alewife, while mercury vapor lights attract alewife. Pagano and Smith (1977) provide a review of this screening concept.

In some circumstances artificial light may give predators an advantage over prey, especially with migrating prey moving into a well-lit area at night with poorly adapted light (photopic) vision. These results coupled with the moderately high turbidity of the Sacramento River led to a decision to reject this concept.

Chains and Cables - Dangling chains and cables have been used in an attempt to guide fish, with and without electricity. Brett and Alderdice (1958) describe research on guiding sockeye salmon (*Oncorhynchus nerka*) and coho salmon. Laboratory tests were successful, but field applications failed to produce satisfactory results for juvenile fish (Brett and Groot 1963).

Positive Barriers

Positive barriers physically prevent fish larger than a selected "target" size from passing through the barrier.

Horizontal Rotary Drum Screens - Horizontal rotary drum screens represent a well developed screening technology for small agricultural diversions and are commonly used in California and the Pacific northwest.

Horizontal rotary drum screens must have the upper half to one-third of the drum height exposed to air to prevent fish from "riding over the drum," appropriate mesh size to exclude fish, and effective seals at the bottom and side of the drum (Figure 3). These criteria can be met in many situations,

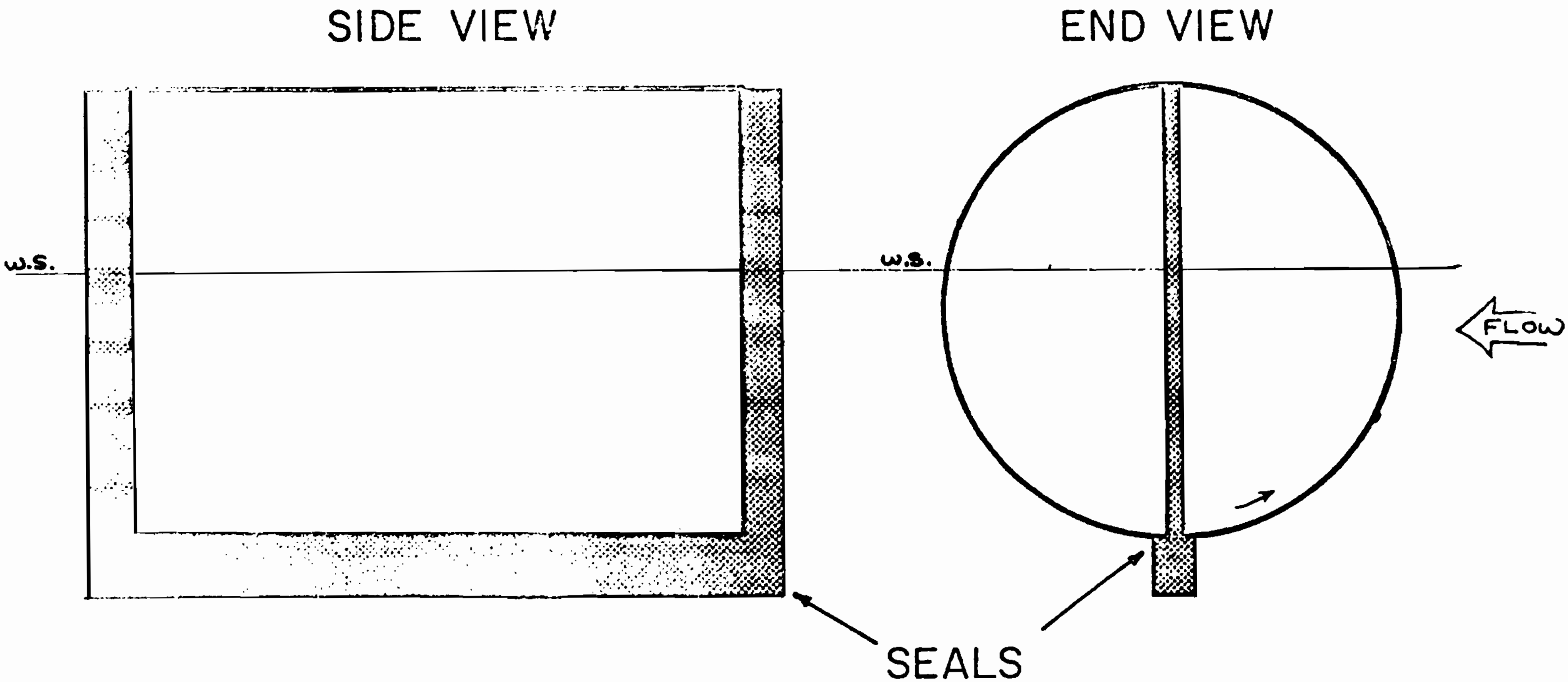


FIGURE 3. Horizontal rotary drum screen showing the location of the seals.

especially when relatively small amounts of water are being diverted. Meeting these criteria at the proposed intake to the Peripheral Canal would have been more difficult, because of the size of the facility and the variable stage of the Sacramento River. Drums would either have to be on the order of 15 m (50 ft) in diameter, or 9.1 m (30 ft) in diameter and move up and down with river stage, or water level would have to be controlled with floodgates in front of the screen. Screen size and movement present difficult and expensive design and operation problems, while floodgates are undesirable because of the high velocities created. These problems resulted in a decision to reject this screening concept (Fish Facilities Technical Coordinating Committee 1969b). A detailed description of two such installations is presented later in this report.

Vertical Drum Screens - The vertical drum screen is similar in concept to a horizontal drum but need not rotate. Vertical drums can be located along the bank or in the intake channel.

Major disadvantages include the withdrawal of water through the drums into large underground tunnels. This is more costly than open channel withdrawal for the horizontal drums. Another disadvantage is the lack of uniform water velocity through all parts of the drum, with the screen approach velocity at the upstream portion of each drum being the channel velocity. Finally, dead areas may be created where predators could maintain themselves.

Drum bearings and seals underwater are potential maintenance problems on rotating drums whereas a rotating cleaning device may be more of a problem to maintain on fixed drums.

These problems, coupled with the lack of a clear biological advantage for vertical drums over flat plates, led us to abandon further efforts on this concept.

Filter Systems - This concept involves exposing flowing water to large porous areas through which water is drawn at a sufficiently slow rate to allow eggs, larvae, and debris to continue downstream past the filter surface. The "filtered" water is carried away from the area by drain pipes and discharged into a collector canal.

The porous area -- or filter bed -- is generally composed of layers of uniformly graded sands and gravels, with size increasing in the direction of water flow. The layers can be built up like a levee (leaky levee), or arranged flat (horizontal filter bed).

To protect eggs and larvae from getting into the filter bed, the velocity of water flowing past the filter bed should be many times the velocity of water going through the filter bed. To maintain movement of eggs and larvae along the filter bed, a velocity of approximately 1 fps may be required. To prevent movement of filter bed materials, a velocity less than 4 fps may be required.

The filter bed can be constructed with or without a cleaning mechanism. Backwashing with water, air, or a combination of both is probably the best method for cleaning sand filters. Cleaning allows higher inflow velocities while maintaining a minimum headloss. If no cleaning is provided, lower inflow velocities will be required and headloss can accumulate as the filter bed clogs.

A filter bed on a slope cannot be backwashed because the filter material would eventually end up at the bottom of the slope. Therefore, a "leaky levee" design, limited in height by minimum river water surface elevation, could mean many miles of levee. This type of design does not therefore appear feasible.

The potential feasibility of a horizontal filter bed system was investigated in 1973 by the Department of Water Science and Engineering, University of California at Davis (UCD) under a contract with DWR. The study by UCD considered a high capacity sand filter without backwashing or mechanical cleaners and was limited to a literature survey and to computations required for a preliminary model of the system. A report was completed in November, 1973 (DeVries 1973) which stated that the filter system appeared potentially feasible but that much more research and development was required.

Time constraints for developing a screening system for the Peripheral Canal, the availability of other technological and operational solutions, the lack of adequate cleaning mechanisms for a filter, and the large filter area needed for the Peripheral Canal diversion led to a rejection of this screen concept. Subsequently the American Society of Civil Engineers (Mussali et al. 1981) recommended against the use of filters for screening water diversions.

Horizontal Traveling Fish Screen - The concept of the horizontal traveling fish screen (HTFS) was described by Bates (1970) and progressed through several models to a Model 7 (Figure 4) which was tested at a facility on the Grande Ronde River near the town of Troy, Oregon. The model consisted of a series of vertical screen panels which continuously moved along a triangular track. The leg moving downstream traveled diagonally across the current and the leg moving upstream was parallel to the intake channel. Fish, eggs, and debris coming downstream were carried or guided into a bypass. The mesh size of the screen panels could be varied, depending on the size and swimming ability of the organisms to be protected.

The HTFS was tested most thoroughly at the Troy facility. The results of these tests have been published (Prentice and Ossiander 1973; Farr and Prentice 1973). The test flume was 76 m (250 ft) long by 12 m (40 ft) wide, and 4 m (15 ft) deep. The 48 screen panels were covered with eight mesh, 0.7 mm (0.03 in.) diameter galvanized wire cloth having a 2.5 mm (0.1 in.) clear opening, with a total open area of 60.2%. The test fish were hatchery-reared spring chinook salmon in four size groups -- 170 mm (6.7 in.), 70 mm (2.8 in.), 35 mm (1.4 in.), and 26 mm (1.0 in.) total length. The authors tested approach velocities of 15 to about 90 cm/s (0.5 to 3.0 ft/s).

The biological tests demonstrated that about 97% of the fry and fingerling chinook salmon were bypassed at approach velocities of 15 and 46 cm/s (0.5 and 1.5 ft/s). Fry, both sac and buttoned-up, readily impinged on the screen at both approach velocities. Survival of the impinged fry was a function of approach velocity with mortality being independent of impingement time at an approach velocity of 15 cm/s (0.5 ft/s); however, at 46 cm/s (1.5 ft/s)

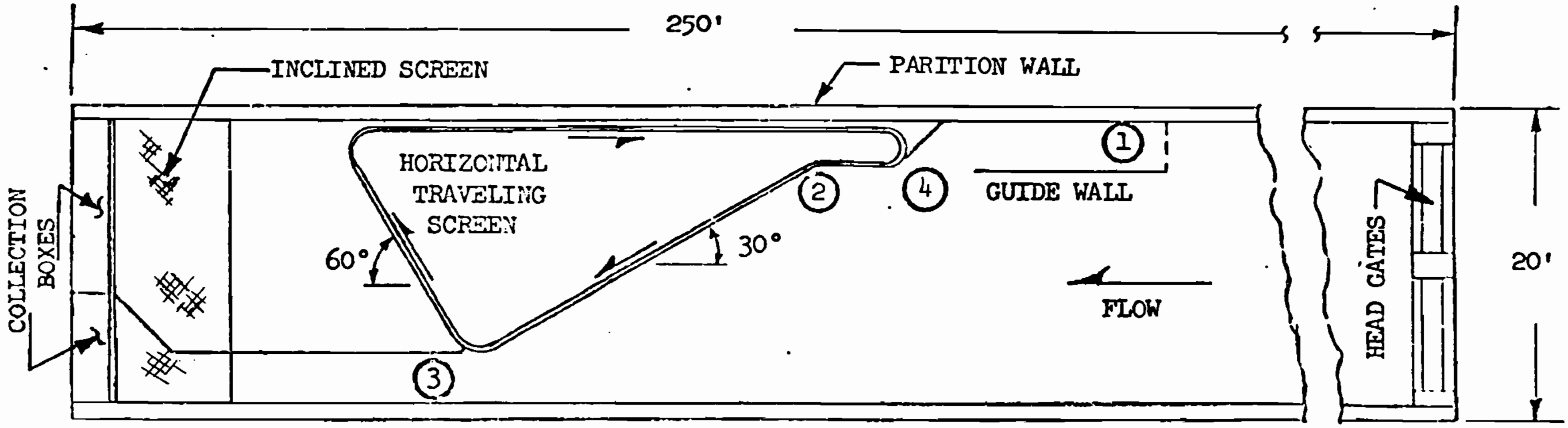


FIGURE 4. Plan view of Troy Test Flume, showing installation of HTS VII and inclined screen (from Prentice and Ossiander, 1973)

survival decreased as impingement time increased from 6 to 60 min. Fingerlings were not impinged at either approach velocity.

As is apparent from the above material, the HTFS demonstrated biological potential, although some fish escaped through openings around the screen panels. Ultimately the most significant problems with the HTFS were mechanical, associated with the large number of moving parts in the structure and the need for continuous operation. The panel support (sliding connections) were subject to considerable wear. The panel hinges created problems, especially on turns and at higher approach velocities. Lubrication of the underwater fittings proved to be difficult. Finally, debris, sand, and silt collected in the underwater track, jamming the screen. The overall conclusion on the mechanical aspects of the Model 7 HTFS at Troy was that there were problems, but that they could be worked out given enough time.

About the time the HTFS was being tested at Troy, PG&E installed a similar screen at the Van Arsdale Dam on the Eel River (Brian Waters, PG&E Biologist, pers. comm.). During the initial operation at this facility, PG&E found that the HTFS diverted fish successfully but that mechanical problems hampered its operation. Some of the mechanical problems were resolved; however, PG&E biologists and engineers never resolved the problem of sediment, debris, and gravel clogging the track and slowing and/or stopping the screen. This screen has since been replaced with a louver screen.

Finally, the Fish Facilities Program constructed a model for testing at Byron, but was prevented from completing the testing program by the lack of success in solving the basic mechanical problems which have plagued this screen concept. For these reasons, this screening concept was rejected.

Vertical Traveling Screens - This screen concept employs screen panels attached to endless chain belts that revolve in the vertical plane between two sets of sprockets (Figure 5). Vertical traveling screens have been installed at many steam electric power plants, mainly for debris control. These screens usually operate intermittently, depending on the debris load and resultant headloss.

A modified vertical traveling screen has been installed at the Surry Power Station in Virginia. The screen was designed to decrease fish mortality due to impingement by equipping each panel with a bucket or trough to retain fish and changes to allow continuous operation. This design has effectively reduced mortality among impinged fish at the Surry site (White and Brehmer 1976). A major disadvantage of this screen concept is that fish have to be impinged prior to collection.

Pagano and Smith (1977) describe numerous modifications that have been tested on vertical traveling screens. The main function of the screen, however, remains debris removal (Maxwell 1973). The large number of these screens (with accompanying mechanical problems) which would be required for the Peripheral Canal (Ecological Analysts 1981) and the requirement that fish be impinged on the screen led to abandoning this concept.

Fixed Screens - Fixed screens can be designed in a variety of shapes and orientations. Some, such as the sawtooth design ("V"), incorporate

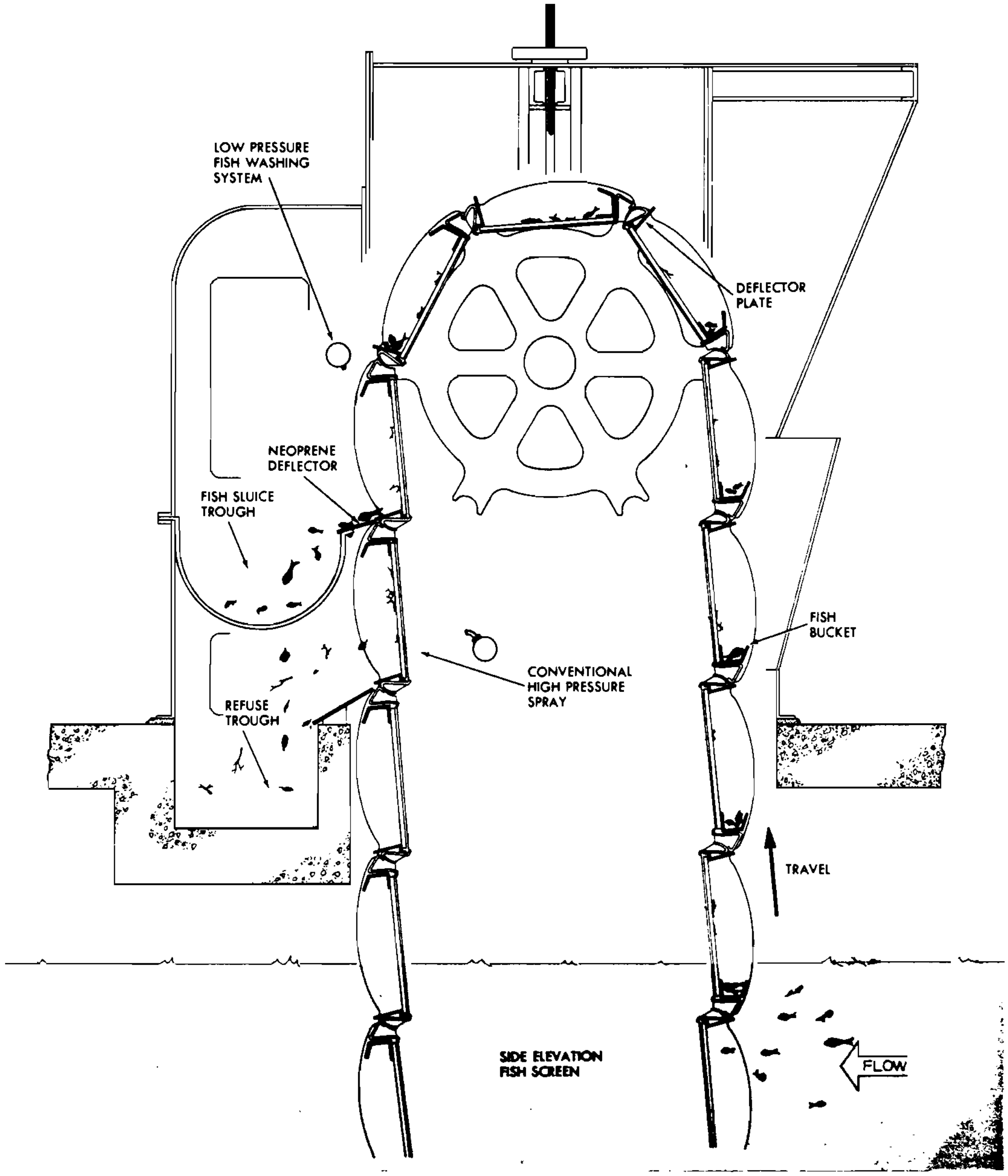


FIGURE 5. Ristoph modified traveling screen with fish buckets, a modified spray water systom, and a sluiceway for fish (Envirex, Inc)

guidance concepts to lead fish into a bypass. Fixed screens considered for the intake to the Peripheral Canal included a flat plate along the bank, either vertical or sloping, and a vertical screen in a sawtooth configuration. A horizontal flat plate set on an incline (Inclined Screen) was also considered.

Plate Along One Bank - This design is desirable from an engineering standpoint in that structural complexity is minimized and maintenance access is relatively simple. Potential disadvantages of this screening system are the length of screen required to provide the low velocities needed to minimize impingement, the exposure of fish to the screen for long periods, and the accumulation of debris along the screen face (Figure 6). Placing the screen at an angle (sloping it from the toe back to the bank) would decrease the length of plate.

Sawtooth - This configuration compresses the space needed for the intake and shortens the time fish are exposed to the screen. The disadvantages relate to the complexity of the bypass system and the fact that it is more difficult to draw the screened water into a canal if the bypass channels remain at full depth (Figure 7).

Inclined - This screen concept bypasses fish near the water surface. Small inclined screens (vertical rise of less than five feet) have been in operation for many years and results are often excellent for screening juvenile salmon when the velocity through the plate is less than 12.1 cm/s (0.4 ft/s) (Coots 1956). The ability of fish to climb an incline in excess of 6 m (20 ft), the rise required for the Peripheral Canal intake, has not been investigated. In light of the fact that fish have difficulty in adapting to rapid hydrostatic pressure changes due to involuntary vertical changes in position, another biological testing program would be needed before inclined screens could be properly evaluated. On the basis of this testing requirement, and the high probability of success for the other two concepts, further investigation of this screen configuration was terminated in 1981.

SACRAMENTO RIVER AT HOOD

The following material provides the reader with a brief description of the Sacramento River near the town of Hood where the Peripheral Canal intake would have been located. Included in this description is information related to physical setting, flow and velocity, tidal effects, suspended materials, and water quality.

Channel Configuration

Figure 8 is a map of the Sacramento River near Hood. The intake site would have been about 25 km (16 mi) below Sacramento and was selected to take advantage of certain hydraulic characteristics of the bend in the river channel. Channel cross sections taken by the U. S. Geological Survey on

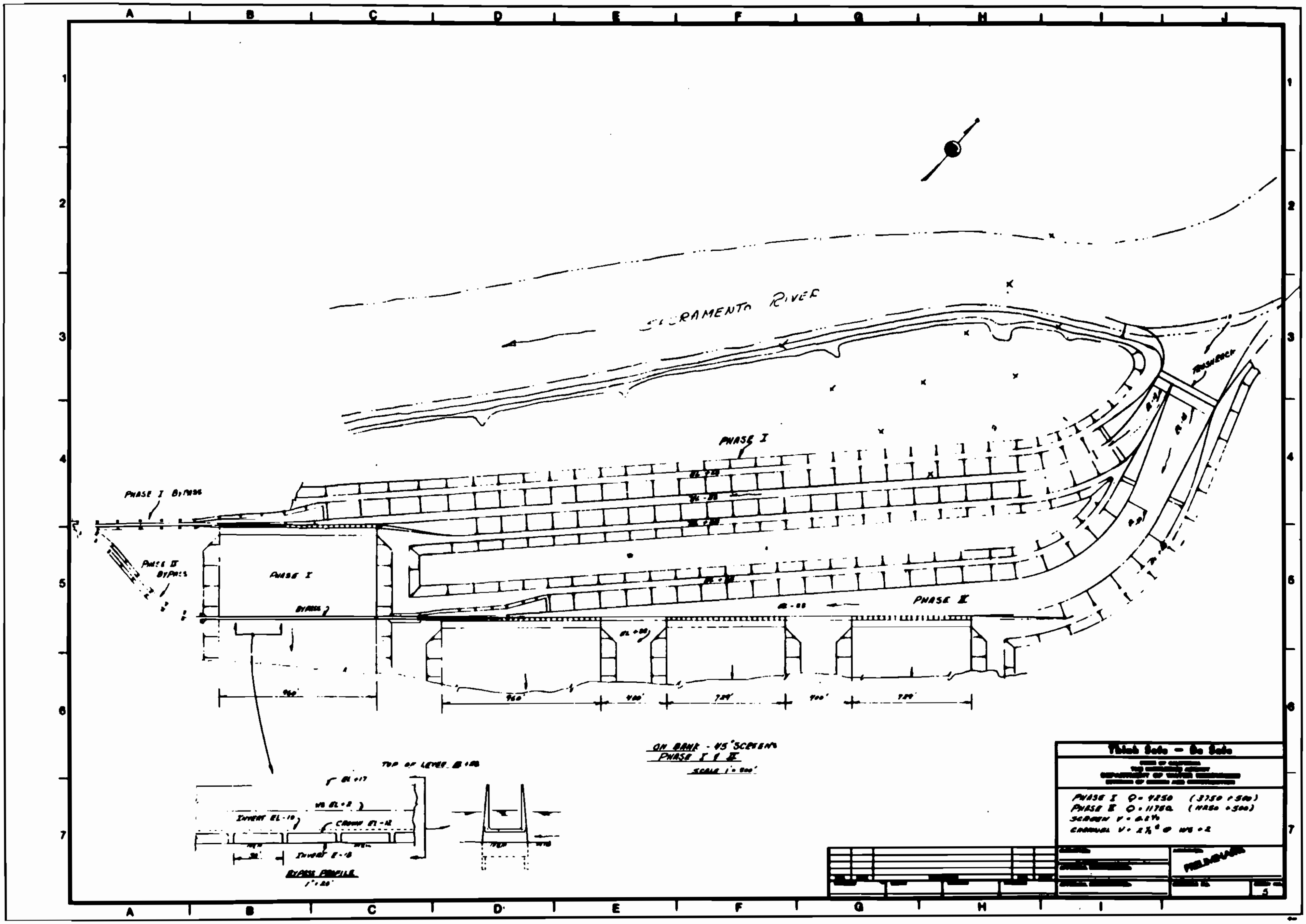


FIGURE 6. Plate along one bank screen concept

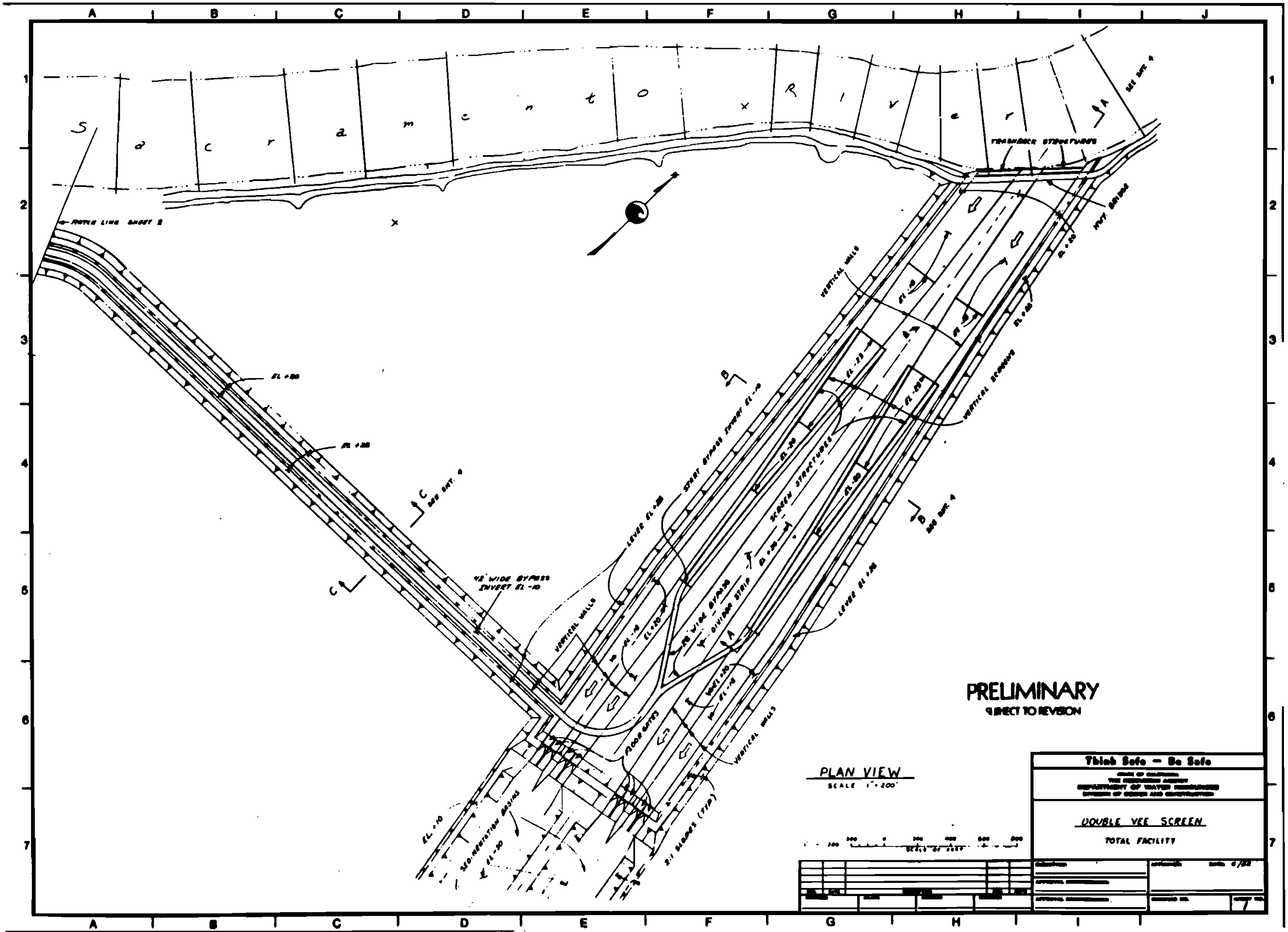


FIGURE 7. Sawtooth fish screen concept

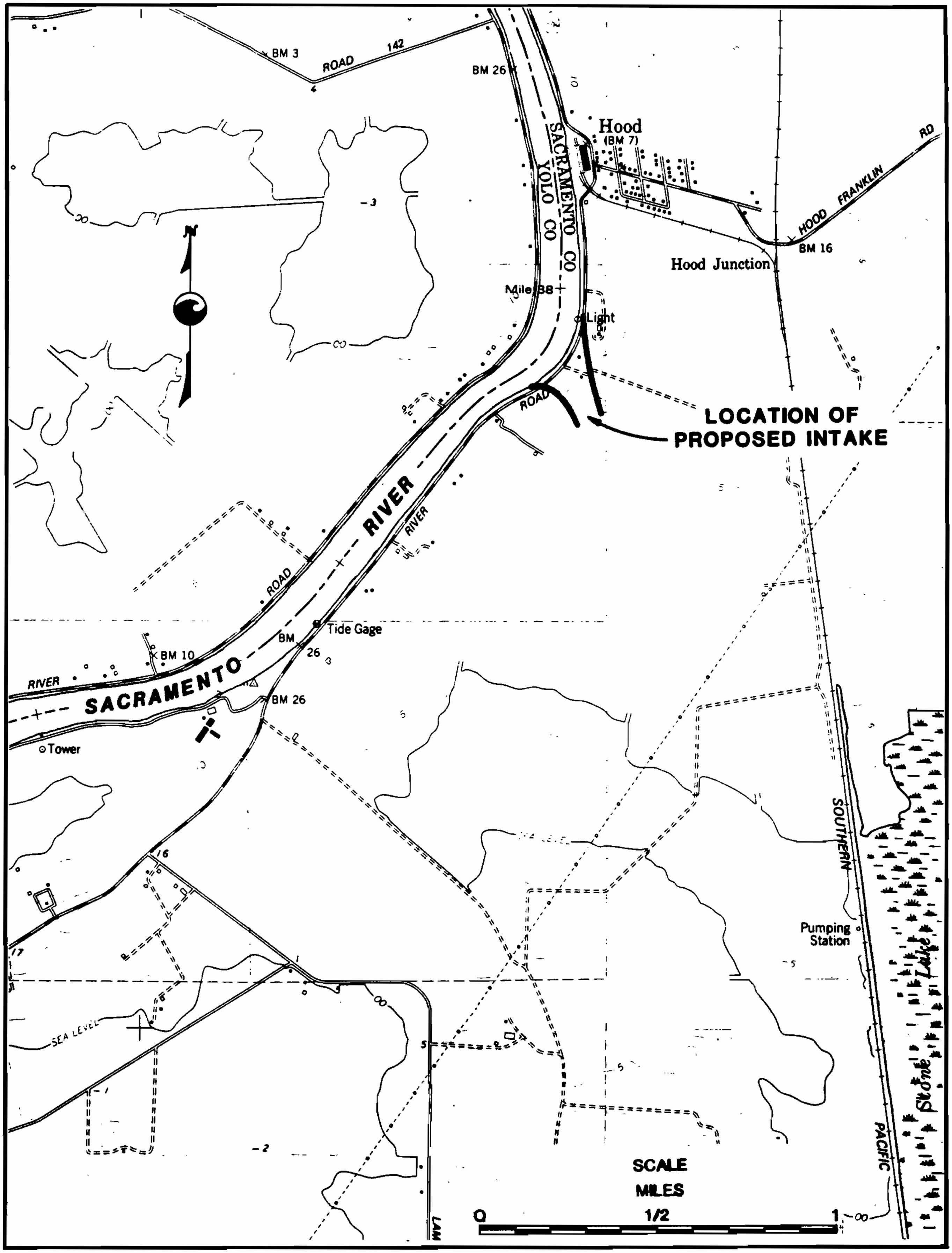


FIGURE 8 MAP OF SACRAMENTO RIVER NEAR HOOD, WITH LOCATION OF PROPOSED INTAKE TO PERIPHERAL CANAL INDICATED

May 11 and 18, 1978, at the upper end of the proposed intake, are shown in Figure 9. The river bottom at the intake site is at an elevation of about -8.5 m (-28 ft) (an elevation of zero is mean sea level). A combination of high flows (greater than 2550 m^3 sec^{-1} [90,000 ft^3 sec^{-1}]) and high tides can cause the water surface to rise to an elevation greater than +5.2 m (+17 ft) while at low flows and low tides the elevation can be less than 0 m (0 ft). Fish protection facilities would thus have had to be designed to handle substantial changes in water surface elevation.

River Flow and Velocity

Figure 10 contains plots of the highest and lowest daily flows recorded at the I Street Bridge in Sacramento for the period 1977 through mid-1981 (U. S. Geological Survey, unpub. data). This relatively short period includes a drought year (1976-77 water year) and a wet year (1979-80 water year) and thus provide examples of the extremes in flow one might expect at Hood. Since there are only relatively minor inflows between Sacramento and Hood, the I Street data are assumed valid for the Hood site. As can be seen in the graph, flows ranged from a high of over 2550 m^3 sec^{-1} (90,000 ft^3 sec^{-1}) in January, 1980 to a low of less than 113 m^3 sec^{-1} (4,000 ft^3 sec^{-1}) at the end of the 1976-77 drought. The range in expected instantaneous flows would exceed those shown because tidal variations would be superimposed on the daily river flows.

Table 1 is a tabulation of average monthly flows (operation study data assuming a 1990 level of development, State Water Resources Control Board Decision 1485 and preliminary 2-Agency Fish Agreement are limiting) at the point of diversion, as well as expected rates of diversion, for the five types of water years and an average water year (the types of water years are based on inflow to the Sacramento River drainage base and are defined in Decision 1485). On a monthly average basis, the projected flows range from a high of 1586 m^3 sec^{-1} (56,000 ft^3 sec^{-1}) in a wet year to a low of about 283 m^3 sec^{-1} (10,000 ft^3 sec^{-1}) in a critical year. The range of percent of flow in the Sacramento River at I Street diverted to the Peripheral Canal is plotted in Figure 11 for easier consideration. The amount diverted during the winter and spring months would vary considerably, but generally range between 20 and 70% and averaging 30%. August appears to be a key month in terms of fish facility operation since there is greater than an 80% diversion rate in all years. Whenever stream flow is controlled by releases from storage, flow in the Sacramento River immediately below the Peripheral Canal intake would have varied between 57 and 85 m^3 sec^{-1} (2,000 and 3,000 ft^3 sec^{-1}). These low flows, combined with tidal effects, would result in flow reversals in the river channel which would affect fish movement past the intake.

Instantaneous average river velocities vary from greater than 1.5 m/s (5 ft/s) at higher flows to negative velocities (reverse flow) during low river flows and flood tides. A typical mid-channel velocity profile during a relatively high flow, about 1530 m^3 sec^{-1} (55,000 ft^3 sec^{-1}), is shown below (U. S. Geological Survey, unpub. data). Velocities may exceed 1.5 m/s (5 ft/s) at flows above 1980 m^3 sec^{-1} (70,000 ft^3 sec^{-1}).

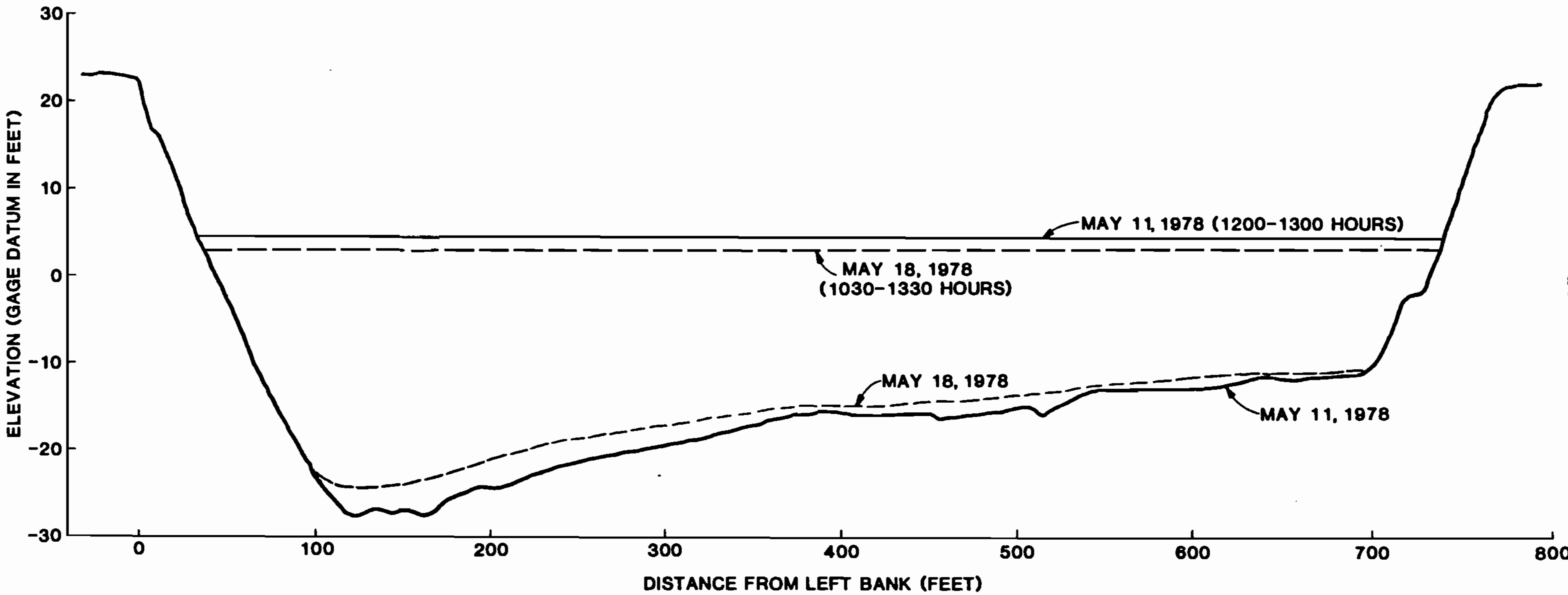


FIGURE 9 CROSS-SECTION NUMBER 2 OF SACRAMENTO RIVER CHANNEL NEAR HOOD

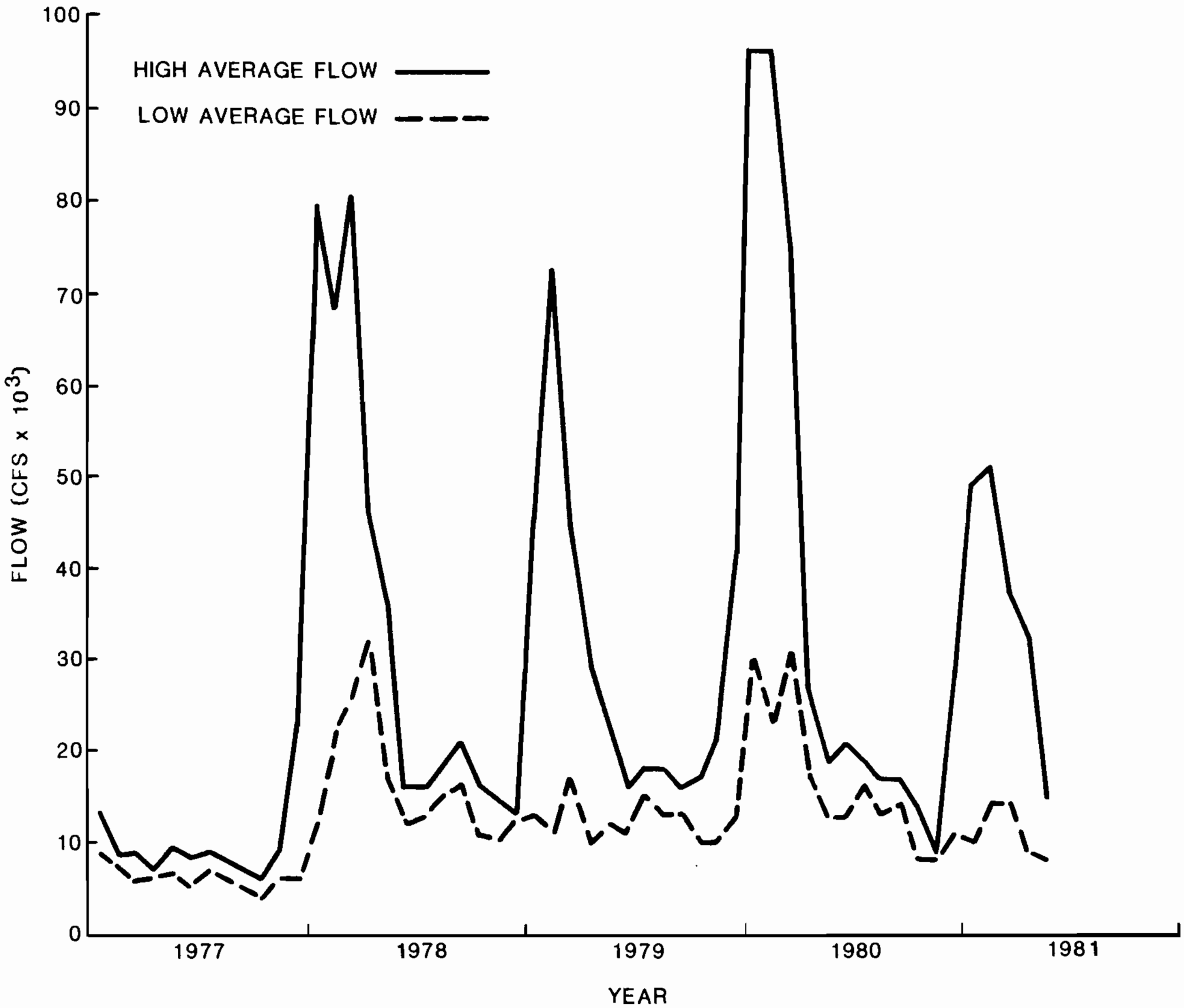


FIGURE 10 HIGH AND LOW AVERAGE DAILY FLOW FOR EACH MONTH FROM JANUARY 1977 THROUGH MAY 1981 SACRAMENTO RIVER AT I STREET (USGS DATA)

TABLE 1

RIVER FLOW AND PROJECTED PERIPHERAL CANAL DIVERSIONS
Monthly Averages For All Years - 1990 Conditions
(Decision 1485 with Fish Agreement Controlling)

Diversion (cfs) / River flow (cfs)

Year Type	J	F	M	A	M	J	J	A	S	O	N	D
Average	9811/29281	9444/36413	6162/29991	8651/21860	5179/21576	11215/19360	12863/17976	12870/15172	10647/14806	9679/13691	9791/14550	9317/21536
Above Normal	11199/21172	10150/31906	8592/35576	10718/23580	4659/19284	10768/18644	13182/18891	12741/15161	10087/14561	9366/12760	9648/13242	9290/17023
Below Normal	8706/16346	9927/32866	8942/27486	8156/13693	4879/16131	10480/16970	14835/18370	13113/15360	11029/14512	9504/13642	9304/14196	7633/14284
Wet	8995/55331	7337/58244	7410/42357	9767/36428	7054/36281	12461/26475	10836/18421	13152/15636	11572/17461	11082/15669	11411/17779	11895/37777
Dry	11061/16738	10963/22675	8639/19371	7008/11611	3906/12213	11782/15182	14679/17538	13348/15468	10435/12934	8723/12543	9107/13328	9010/12955
Critical	9480/12281	10752/13170	7700/10090	6055/9461	3530/9626	8717/12006	13008/15556	11150/13180	8966/11658	8265/11801	7552/10474	7182/10172

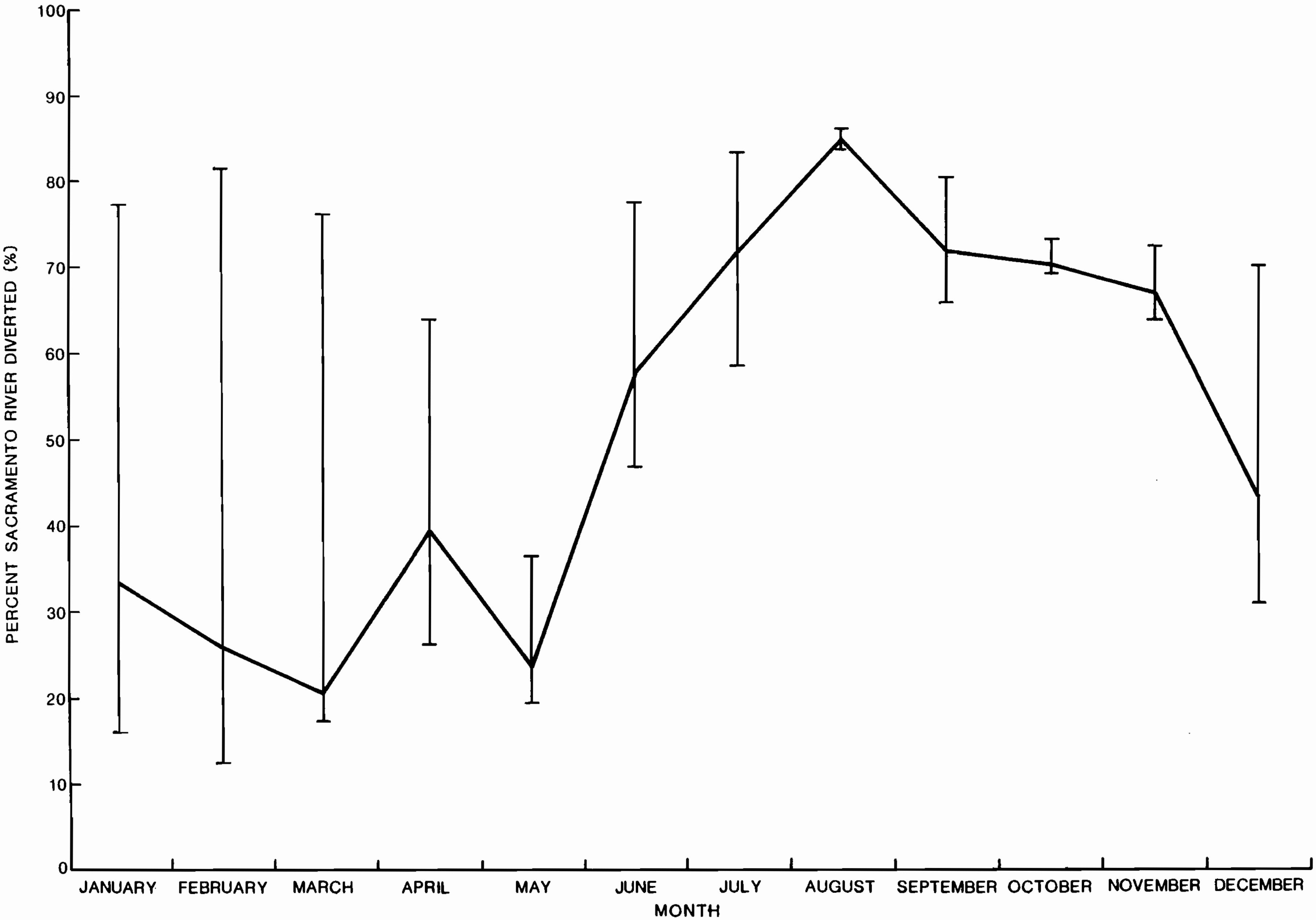


FIGURE 11 AVERAGE AND RANGE OF PERCENT OF SACRAMENTO RIVER FLOWS AT I STREET DIVERTED TO THE PERIPHERAL CANAL (1990 LEVEL OF DEVELOPMENT, D 1485 CRITERIA WITH FISH AGREEMENT)

Depth (m)	Velocity (m/sec)
0.3 (0.98 ft)	1.21 (3.97 ft/sec)
2.0 (6.56 ft)	1.16 (3.80 ft/sec)
4.0 (13.12 ft)	1.11 (3.64 ft/sec)
6.0 (19.68 ft)	0.95 (3.12 ft/sec)
7.7 (25.26 ft)	0.46 (1.51 ft/sec)

Figure 12 shows the range of instantaneous velocities at Hood for river flows up to 680 m^3 sec^{-1} (24,000 ft^3 sec^{-1}). This range of flows is typical of those expected during most of the year at Hood (Smith, MS). Under the reported flow conditions of between 113 and 680 m^3 sec^{-1} (4,000 and 24,000 ft^3 sec^{-1}), in-river average daily velocities can be expected to vary between about 0.12 and 0.67 m/s (0.4 and 2.2 ft/s). (A low flow of 113 m^3 sec^{-1} [4,000 ft^3 sec^{-1}] occurred during the recent 1976-77 drought.)

The velocity data plotted in Figure 13 (USGS, unpub. data) show the variability across the stream channel during a reported flow of 623 m^3 sec^{-1} (22,000 ft^3 sec^{-1}).

Tidal Effects

The tide tables for the Pacific Coast of North America (U. S. Department of Commerce 1980) show a mean annual tidal range of 0.7 m (2.3 ft) for Clarksburg, about 8 km (5 mi) above Hood on the Sacramento River. The change in water surface caused by the tide does cause some design problems; however, the most important effect of tidal variation during low flows is to cause flow reversal at the Peripheral Canal intake. With flow reversal, fish may be exposed to the screens more than one time. Figure 14 shows the changes in river velocity associated with the tidal cycle (Smith, MS). Note that flow reversal did not occur at the 340 m^3 sec^{-1} (12,000 ft^3 sec^{-1}) flow but occurred twice in the tidal cycle at an estimated flow of 198 m^3 sec^{-1} (7,000 ft^3 sec^{-1}). Flow reversal adjacent to the screens in the off-stream channel may be eliminated by pumping in the return channel to achieve a positive downstream flow at all times.

Smith (MS) calculated the percentage of fish initially passing the fish screens that might be recirculated during different year types and with intake and return channels of 457, 1524, or 3048 m (1,500, 5,000, or 10,000 ft) in length (Figure 15). These calculations assume the fish are drifting with the water. In general, the calculations show that it is practically impossible to prevent recirculation in dry and critical years with shorter facilities. The 3048 m (10,000 ft) long fish return channel would eliminate recirculation in all years.

Sediment

Sediment is carried in the Sacramento River as suspended load and bedload. Early planning to deal with this subject included siting the intake structure properly and providing a well designed sill to retain most of the bedload

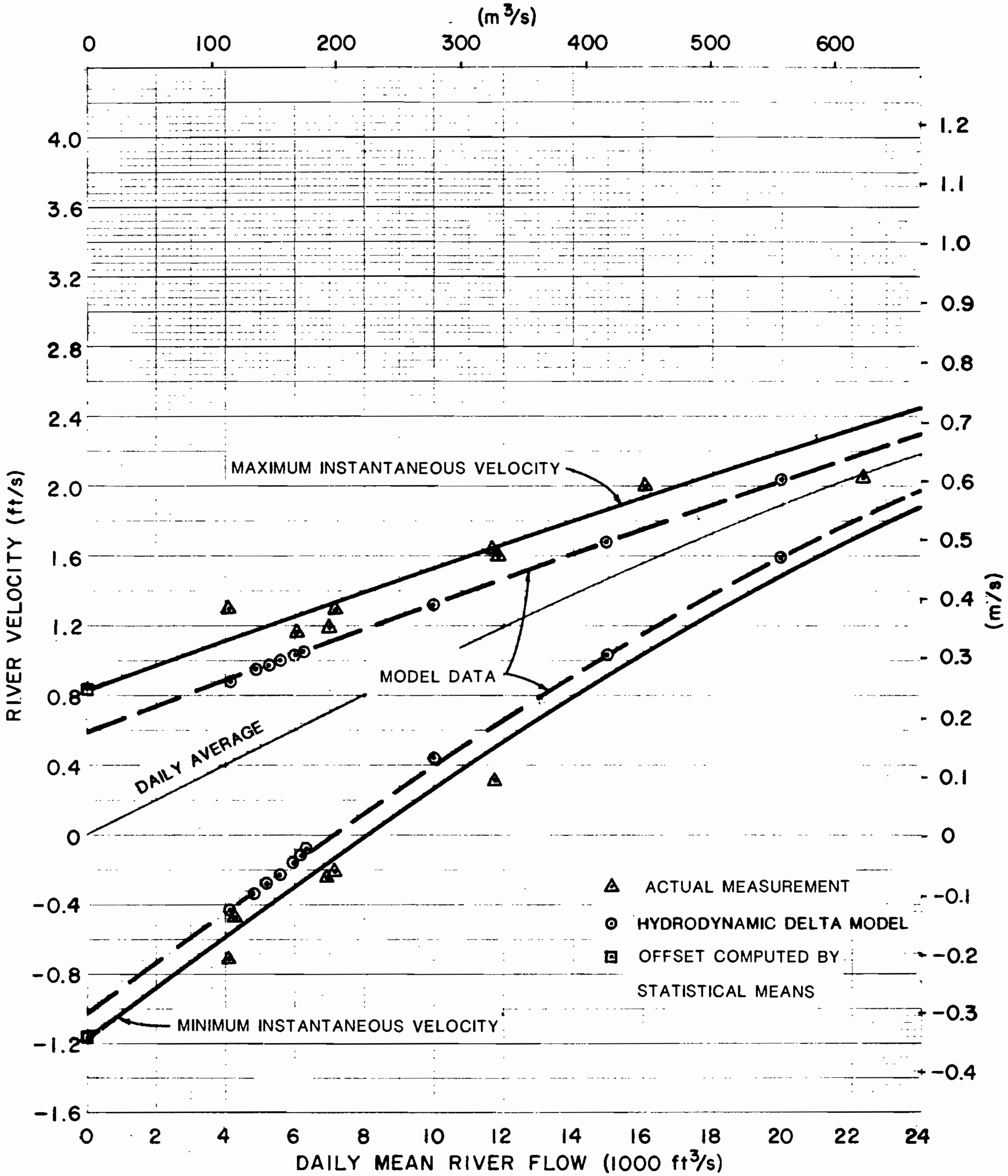


FIGURE 12. Range of instantaneous river velocity at Hood (from Smith, MS)

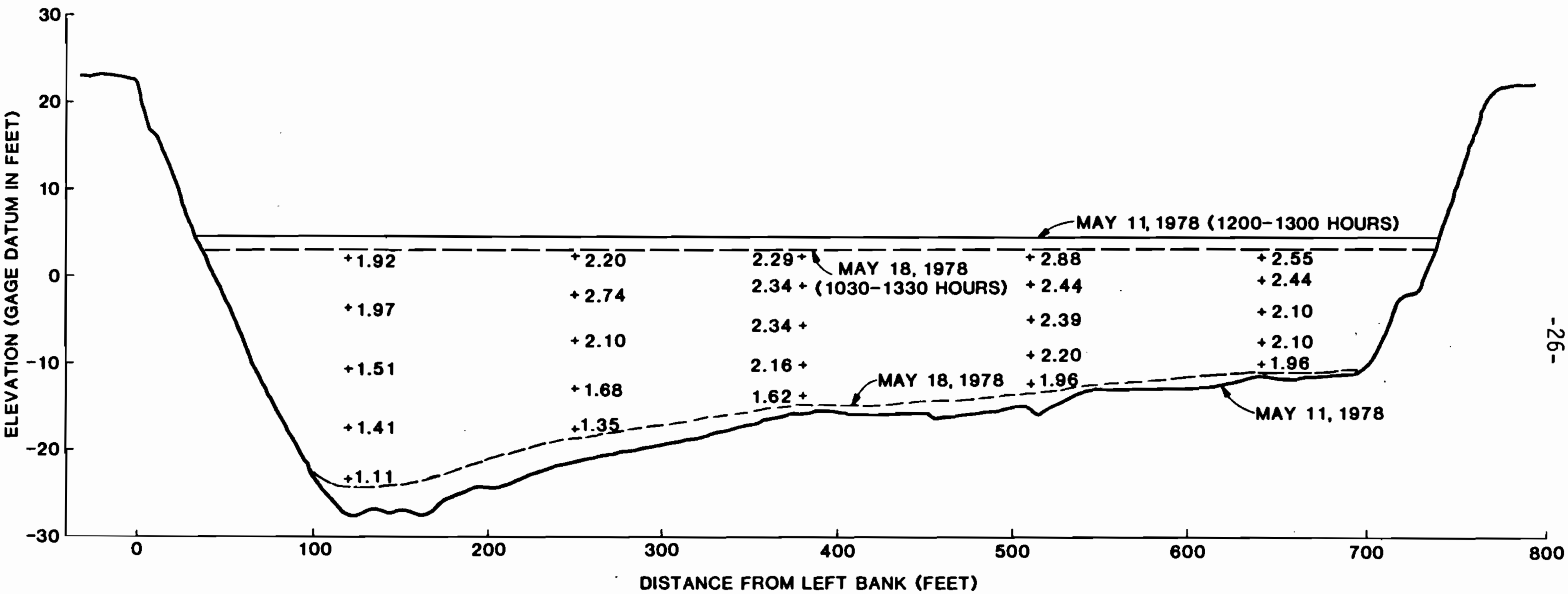


FIGURE 13 VELOCITY-FT/SEC MAY 11, 1978 SACRAMENTO RIVER AT HOOD, CA. CROSS-SECTION NUMBER 2

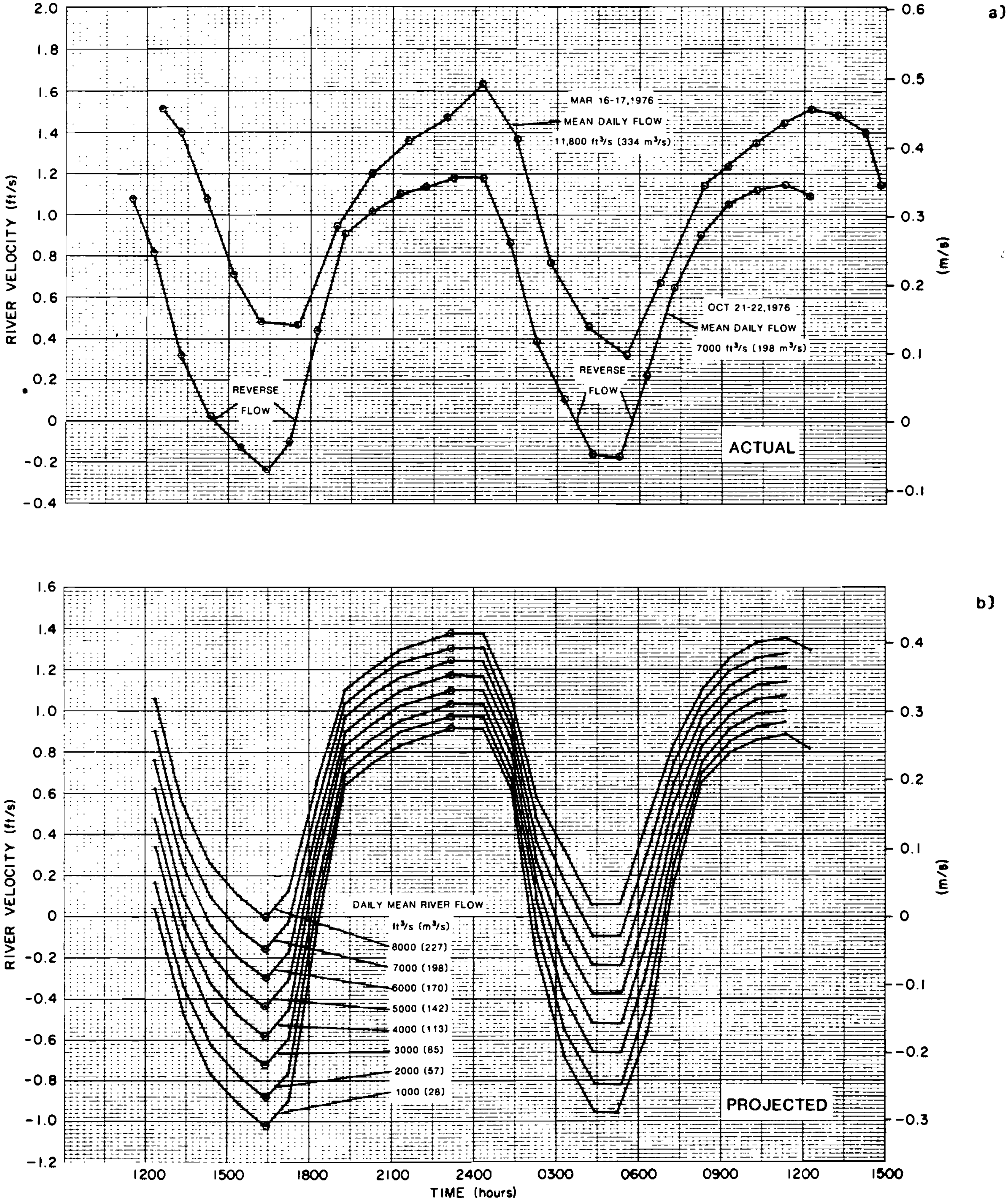


FIGURE 14. Actual and Projected Tidal Cycle Velocities at Hood (from Smith, MS)

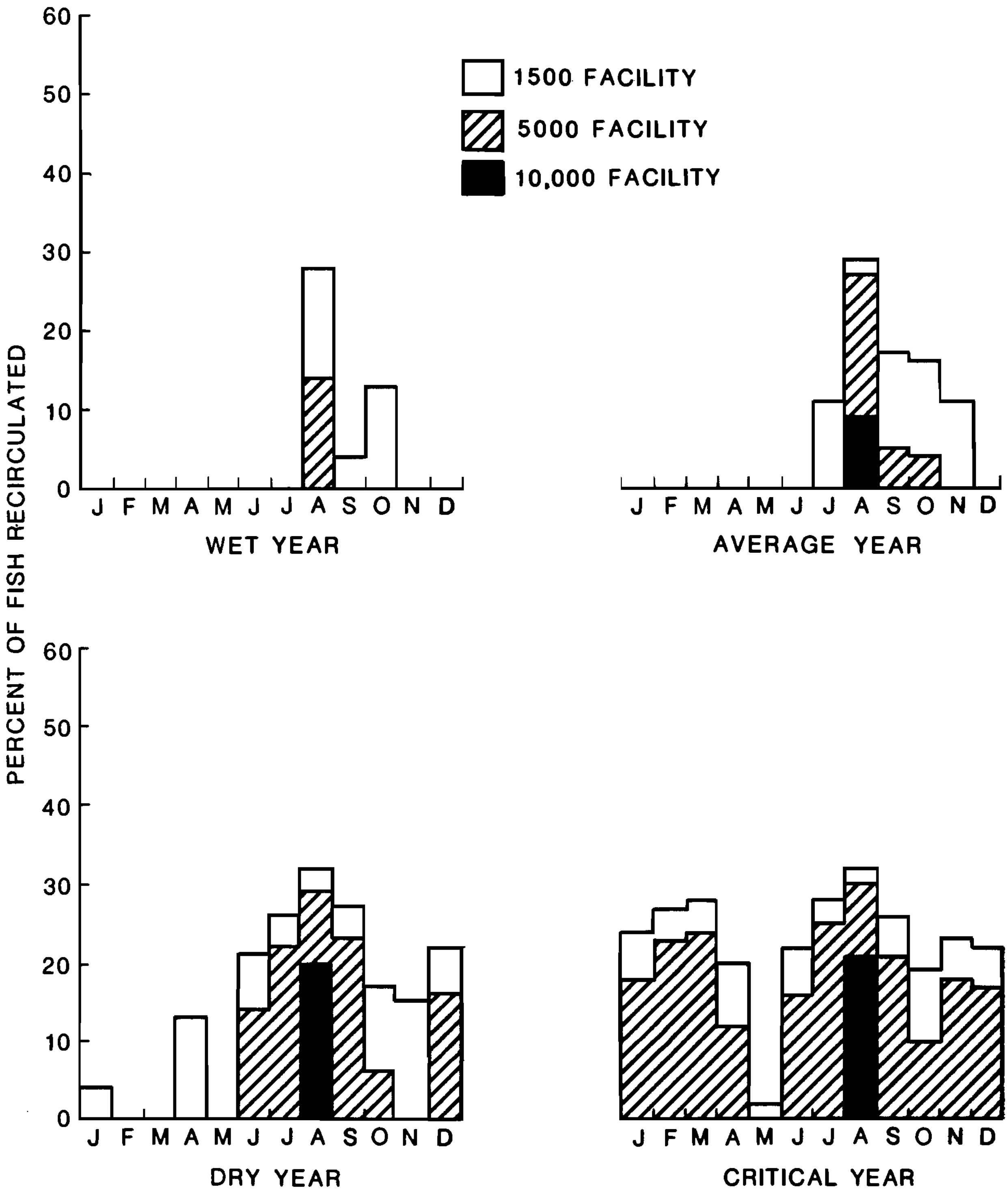


FIGURE 15. Percent of fish passing each day that would be exposed to the fish screen two or more times if fish moved at the same rate as the water. (from Smith, MS)

in the river. Preliminary model studies indicated that by properly locating the intake, the bedload diversion into the intake channel could be minimized. A preliminary location for the intake was established from these studies.

Later studies with a larger scale model indicated severe problems with flow patterns at the selected intake site, resulting in modifications in an attempt to minimize this problem. These modifications could result in the diversion of some bedload material into the facility.

Suspended sediment would be diverted into the facilities with the water and most could be carried through the structures by maintaining proper velocities. Most of this material could then be deposited in a settling basin located between the fish screens and the pumping plant. Considerable quantities of sediment would be deposited in the river immediately downstream of the intake structure. Most would be washed out during high flows, however maintenance dredging would also be required at this location.

Sedimentation, as related to the Peripheral Canal intake, has been described by Graves (1977). The measured suspended sediment load in the Sacramento River at Sacramento from 1957 through 1973 was (from Graves 1977):

Year	Suspended sediment 1000 metric tons (short tons)
1956-57	1515 (1669)
1957-58	4539 (5000)
1958-59	1686 (1857)
1959-60	1594 (1756)
1960-61	1764 (1943)
1961-62	1821 (2006)
1962-63	3582 (3946)
1963-64	970 (1069)
1964-65	5160 (5684)
1965-66	1875 (2065)
1966-67	3007 (3312)
1967-68	1454 (1602)
1968-69	3136 (3454)
1969-70	2533 (2790)
1970-71	2918 (3214)
1971-72	762 (839)
1972-73	2358 (2598)

A compilation of estimated sediment production in the Central Valley for the past 100 years leads to a conclusion that annual suspended sediment production is on the decrease and should stabilize at about 1,815,600 metric tons (2,000,000 tons) per year by 2020 (Graves 1977).

As expected, most of the annual sediment yield occurs during the winter and spring months, with about 70% coming down in the 4-month period of December-

March. Combining suspended sediment load, flow, and diversion rates into the Peripheral Canal, the following monthly estimates of suspended sediment diversion are obtained (2020 level of development):

	Suspended sediment 1000 metric tons (short tons)	
Month	In-river	In-canal
October	40 (44)	27 (30)
November	36 (40)	25 (28)
December	248 (273)	119 (131)
January	497 (547)	178 (196)
February	307 (338)	140 (154)
March	367 (404)	162 (178)
April	94 (103)	50 (55)
May	78 (86)	26 (29)
June	44 (48)	39 (43)
July	44 (48)	41 (45)
August	56 (62)	51 (56)
September	74 (81)	44 (48)
Total	1885 (2074)	902 (993)

Although the operation studies used to derive these figures are no longer valid, the numbers do indicate that a significant portion of the sediment suspended in the waters of the Sacramento River would be diverted into the Peripheral Canal. Table 2 contains estimates of the size distribution of the suspended materials; a table which could be used in conjunction with predicted canal velocities to estimate the amount of in-canal deposition. Conceptual plans included a sedimentation basin where more than one-half of the suspended sediment entering the canal would settle out (Graves 1977). This sediment (estimated at 454,000 metric tons [500,000 tons] annually, or about one-fourth of that originally found in the Sacramento River) would not be conveyed to the Sacramento-San Joaquin Estuary since it would not be directly returned to the river.

Water Quality

In terms of the fish protection facilities, water quality is important in two ways. First, the water quality should be such that it does not stress the fish. Stresses associated with the intake facility will be unavoidable and should not be compounded by water quality induced stresses if the fish are to survive. Secondly, water quality constituents should not contribute unduly to the growth of aquatic organisms on the screens. Examples of water quality constituents which might contribute to screen fouling are waters with significant amounts of seawater intrusion and those high in plant nutrients such as nitrogen and phosphorus, or high in bacterial nutrients such as dissolved organic material.

TABLE 2.

DISTRIBUTION OF SUSPENDED SEDIMENT ENTERING THE PERIPHERAL CANAL (from Graves, 1977.)

PARTICLE SIZE RANGE MM	GEOMETRIC MEAN SIZE MM	SETTLING VELOCITY FPS *	AVERAGE % IN CLASS	SUSPENDED LOAD 1 000 TONS
> 0.8	-	-	-	-
0.8 - 0.4	0.57	0.225	2	20
0.4 - 0.15	0.24	0.100	8	79
0.15 -0.062	0.10	0.025	12	120
0.062-0.04	0.05	0.006	10	99
0.04 -0.02	0.03	0.002	13	130
0.02 -0.01	0.014	0.005	11	110
< 0.01	-	-	44	432
			100	990

* From Einstein (1950).

A general idea of present water quality is found in Table 3 (U. S. Bureau of Reclamation, unpub. data). These data were collected at Greene's Landing, a few miles downstream from Hood. In general, the data indicate that water quality, at least in terms of the parameters listed, should not be a problem at the Hood diversion facilities. The oxygen and mineral content of the Sacramento River water should not stress migrating fish populations. The nutrient concentrations are such that moderate amounts of periphytic growth can be supported; however, the information on secchi depths demonstrates that light penetration (photic zone) is limited to the top few feet.

Temperature data, not shown in Table 3, indicate that water in the Sacramento River may be too warm for salmon at times. A worse case situation, plotted in Figure 16, shows that water temperatures at Hood were occasionally near 27 C (80 F) during the summer. At these elevated temperatures, some resident and migratory fish would be stressed. The DFG does not normally release hatchery reared salmon into the Sacramento River where the water temperature exceeds 21 C (70 F).

Fish Occurrence and Distribution

Various species of resident and migratory fish are present near Hood. Information on these fish was summarized in two bulletins prepared by the Delta Fish and Wildlife Protection Study (Kelley 1966; Turner and Kelley 1966).

Adult fish migrate past Hood throughout the year, with species of concern including striped bass, American shad, sturgeon, chinook salmon, and steelhead rainbow trout (<u>Salmo gairdneri</u>) (Figure 17).

A midwater trawl and beach seining survey was conducted in the Sacramento River near Hood from February, 1973 to September, 1974 to determine the seasonal occurrence and sizes of fishes passing the site (Schaffter 1980). Juvenile chinook salmon were abundant from January through early July. Chinook salmon less than 50 mm (2 in.) fork length (FL) were abundant during January, February, and March. Chinook salmon larger than 60 mm (2.4 in.) FL were most abundant from April to July, and averaged 80 mm (3.2 in.) FL. Juvenile chinook salmon were most abundant in the surface 2 m (6.6 ft) during the daylight and dispersed throughout the water column at night.

American shad eggs and larvae were collected during April, May, and June. Juvenile shad were abundant from July through October. The majority of the shad was collected in the mid-river and west bank trawl corridors. Mean size of American shad ranged from 30 mm (1.2 in.) in July to 90 mm (3.5 in.) in October (Schaffter 1980).

Over 80% of the post-larval striped bass that were collected were between 90 and 200 mm (3.5 to 7.9 in.). Fewer than 8% of all post-larval striped bass collected were considered to be young-of-the-year (Schaffter 1980). All but a trace of the young-of-the-year striped bass that passed Hood were less than 6 mm (0.2 in.) (Schaffter, MS), a developmental stage when swimming ability is non-existent or only adequate for minimal regulation of depth (Mansueti 1958).

TABLE 3

WATER QUALITY CONDITIONS IN THE
SACRAMENTO RIVER AT GREENE'S LANDING 1/
1969-1974

	Mean	Standard deviation	Maximum	Minimum
Secchi (inches)	20.6	7.9	36	4
Sp Cond (µsiemens)	142.3	28.6	236	64
DO (mg/l)	9.3	1.2	12.4	7.0
T alk (mg/l as $CaCO_3$)	42.4	18.4	75	19
TDS (mg/l)	100	21.9	150	72
OrgN (mgN/l)	0.44	0.39	1.5	1.9
NH_3-N (mgN/l)	0.08	0.03	0.17	0.02
NO_3-N (mgN/l)	0.65	0.81	2.0	0.09
Ortho P (mgP/l)	0.06	0.02	0.10	0.0
Ca^{++} (mg/l)	10.4	1.2	13	8.1
Mg^{++} (mg/l)	6.0	1.3	9.0	2.9
Na^{+} (mg/l)	8.8	2.6	16.0	4.4
K^{+} (mg/l)	1.3	0.27	1.8	0.8
Cl^{-} (mg/l)	7.2	8.6	69	1
$SO_4^{=}$ (mg/l)	7.9	1.9	12	4.1
HCO_3^{-} (mg/l)	58.9	20.3	98	23

1/ U. S. Bureau of Reclamation, unpublished data.

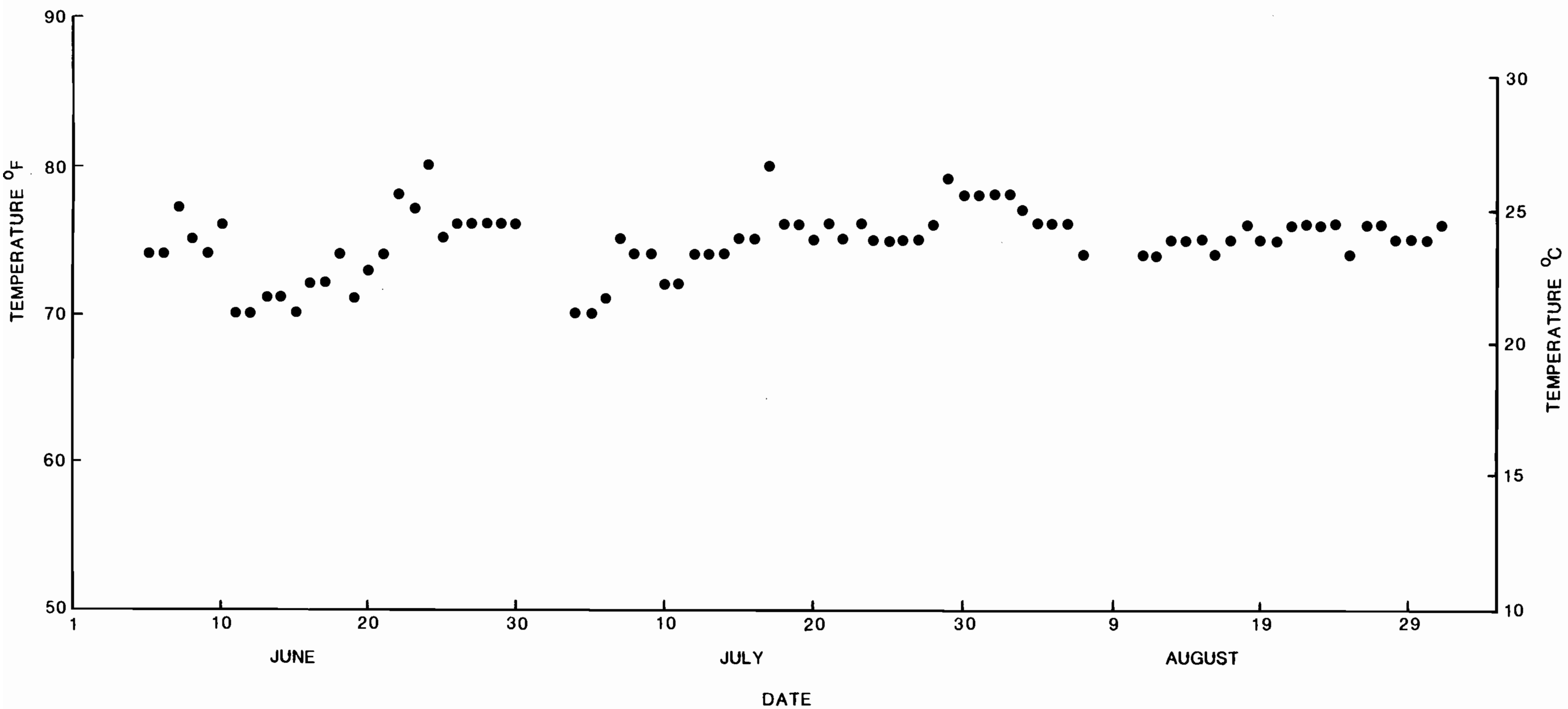


FIGURE 16 OBSERVED TEMPERATURE OF SACRAMENTO RIVER WATER, SUMMER OF 1977

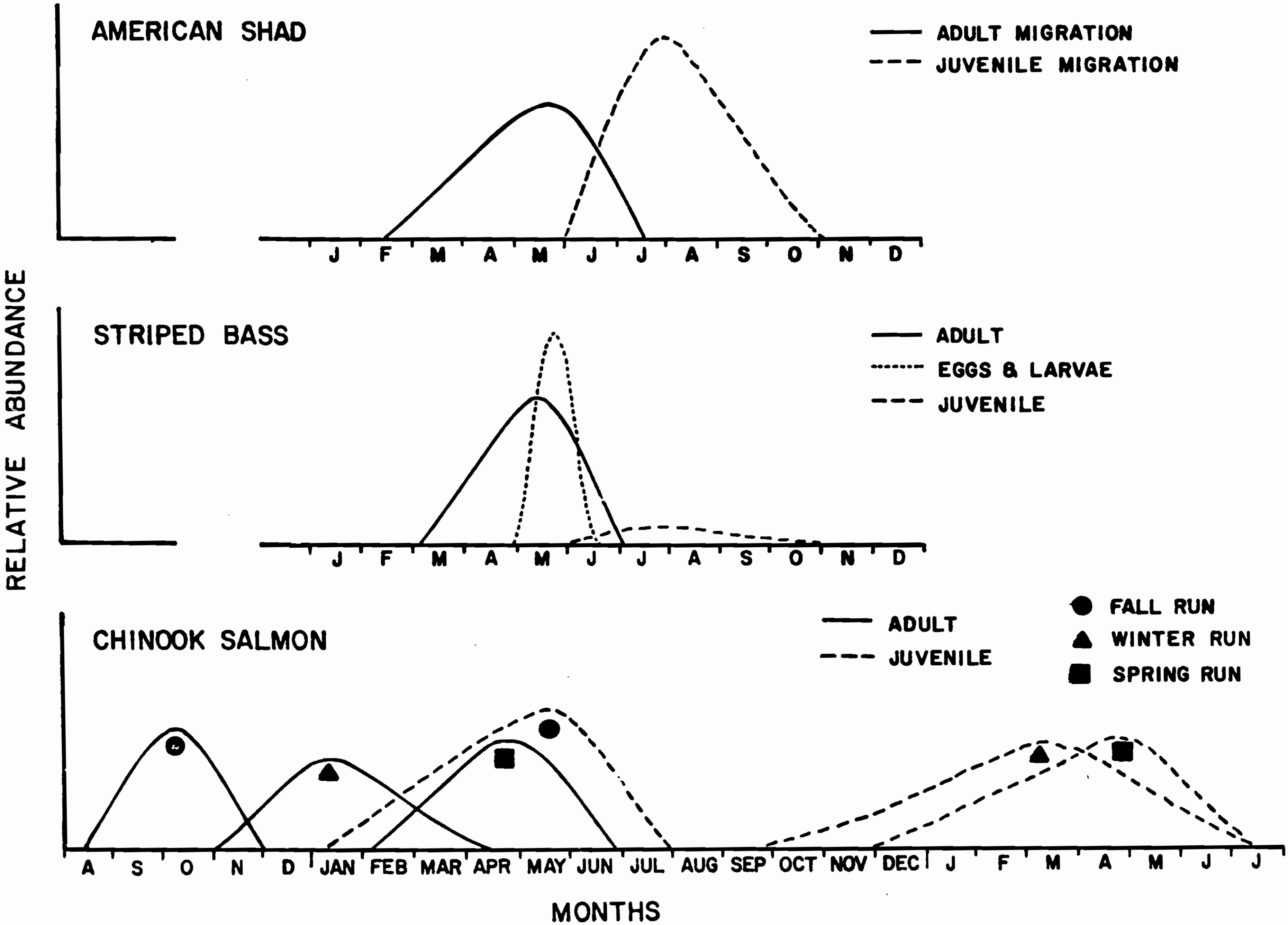


FIGURE 17. Generalized fish migration past Hood on the Sacramento River.

Although no sturgeon were collected during Schaffter's trawl survey, the majority of the sturgeon spawning occurs in the Sacramento River above Knights Landing during mid-February to late May (Kohlhorst 1976). All the larvae and juveniles pass Hood on the way to the nursery in the estuary. The only record of the size of sturgeon passing the intake is presented by Stevens and Miller (1970) and shows that a few larvae down to 10.9 mm (0.4 in.) were caught in the Delta below Hood during high outflow years.

BIOLOGICAL TESTING PROGRAM

The activities of the biological testing program conducted by the staff of the DFG are reported by the various subject areas.

Evaluation of Existing Facilities

Evaluations at existing facilities have included establishing the efficiency of these installations and modifying the installations to either improve screening efficiencies or test the results of other studies in a field situation.

Glenn-Colusa Fish Screen

The Glenn-Colusa fish facility is a horizontal rotary drum screen installation located on an oxbow of the Sacramento River approximately 6 km (3.7 mi) northwest of Hamilton City. The screen complex consists of forty 5.2 m (17 ft) diameter, 2.4 m (8 ft) wide horizontal rotating drums covered with 4.3 mm (11/64 in.) square mesh stainless steel wire cloth. The maximum diversion is 76.5 m^3/s (2700 ft^3/s) and the designed approach velocity to the screen is 0.2 m/s (0.8 ft/s). There are ten 15.2 cm (6 in.) wide bypasses, one at the downstream end of every fourth screen. After 3 years of evaluation (Decoto 1978; DFG, unpub.) the following conclusions were reached:

1. The screen bypasses were approximately 50% as efficient in bypassing juvenile salmon as a pair of 0.9 m (3 ft) diameter culverts we installed in the earthen diversion dam downstream in the oxbow as an alternate bypass.

2. Losses associated with the trashrack structure may have reduced the recoveries of juvenile salmon by 20% to 25%.

3. Screen leakage was identified and persisted despite efforts to stop it. These efforts included installing wiper blades to prevent fish from riding over the top of the screen and providing smaller mesh screen material. Leakage was presumed to be due to inadequate seals since the fish could not go through or over the screen.

4. The lack of an adequate bypass reduces the overall effectiveness of this installation.

5. Predation by resident and migratory fishes may be responsible for substantial losses of young salmon at the screen complex.

Woodbridge Fish Screen

The Woodbridge fish facility is another horizontal rotary drum screen installation located on the Mokelumne River at the town of Woodbridge. The screen complex consists of seven 3 m (10 ft) diameter by 2 m (6.5 ft) wide horizontal rotary drums. The mesh size of the screen under investigation was 6.4 mm (0.25 in.). The designed approach velocity is 0.18 m/s (0.6 ft/s) at 12.7 m^3/s (450 ft^3/s). Fisher (1976b) reported that juvenile salmon "sounded" as they approached the screen and that salmon as large as 40 mm (1.6 in.) were collected in nets immediately behind the screen. Since the seals appeared to be adequate, Fisher concluded the fish were "escaping" through the screen mesh. The conclusion is supported by mesh retention test results which were run concurrently and showed that 40 mm (1.6 in.) salmon could pass through 6.4 mm (0.25 in.) mesh screens (Fisher 1978).

Tracy Fish Collection Facility

The Tracy fish facility is a louver screen installation located 9 miles northwest of Tracy at the intake to the Delta-Mendota Canal on Old River (Figure 1). The fish facility is composed of two louver systems in series which divert fish from the canal concentrating them into holding tanks. The primary louvers have a 2.5 cm (1 in.) opening and the structure is 97.5 m (320 ft) long and 7.6 m (25 ft) high. The diversion channel capacity is approximately 142 m^3/s (5000 ft^3/s) and the channel velocity to the primary louvers ranges from 0.1 to 1.2 m/s (0.4 to 4.0 ft/s) depending on the quantity of water diverted. The primary louver array has four 15.2 cm (6 in.) bypasses spaced 22.9 m (75 ft) apart. The secondary channel has two rows of louvers in tandem that guide fish into a single bypass from which they are conveyed to the holding tanks. Fish from the holding tanks are transferred to trucks and hauled to release sites in the Delta.

The facility was evaluated by Bates, Logan, and Pesonen (1960). They concluded that collection efficiency ranged between 65 and 90% depending on fish species and time of the year. In a subsequent evaluation conducted during 1966 and 1967, the overall efficiency for striped bass was determined to be 71%, and for striped bass less than 22 mm (0.9 in.) efficiency was as low as 64% (Hallock, Iselin, Fry 1968).

The facility was re-evaluated in 1973 based on the results of the testing program at the State facility and the higher channel velocities which were the result of increased exports. The efficiency for striped bass less than 19 mm (0.8 in.) was estimated to be 25% while the overall efficiency for striped bass was probably less than 50% (Heubach and Skinner 1978). The authors estimated the efficiency for juvenile chinook salmon to range between 77 and 83%.

Studies were conducted during 1973 to 1976 to determine the mortality associated with the handling and trucking of juvenile chinook salmon. Mortality of fish that were "collected" and transported by truck to the release site was approximately 50% greater than the mortality of fish that were transported from the hatchery without handling at the facility (Menchen 1980).

John E. Skinner Delta Fish Protective Facility

The Delta Fish Protective Facility screens the California Aqueduct for the SWP (Figure 1). Present intake capacity is 178 m^3 sec^{-1} (6300 ft^3 sec^{-1}). It is located on Old River near the town of Byron, California. The basic design is similar to the Tracy Fish Collection Facility employing a primary and secondary louver array for diverting fish from the aqueduct. There are two major differences between the Delta Facility and the Tracy Facility. The Delta Facility is preceded by a $3.5 \times 10^7 m^3$ (2.9×10^4 acre-foot) forebay and the primary louvers at the Delta Facility are arranged in a sawtooth. The facility was evaluated during 1970 and 1971 (CDWR and CDFG 1971; Skinner 1974b). The efficiencies for chinook salmon ranged between 65 and 90%, depending on size of fish and channel velocity. The overall efficiency for striped bass was approximately 69%, however the efficiency varied from about 5% for striped bass less than 10 mm (0.4 in.) to approximately 90% for striped bass greater than 130 mm (5.1 in.).

Meinz (1978a) used a test flume to develop configurations and operating parameters that would increase the efficiency of a louver array to successfully guide chinook salmon less than 40 mm (1.6 in.). Variables tested included channel velocities and bypass acceleration ratios. Although the goal of the study was to attain 95% efficiency, he was only successful in reaching 85% efficiency. However, an efficiency of 94% was achieved for salmon greater than 45 mm (1.8 in.). Results of these investigations were used to optimize operational conditions at the State and Federal facilities. Neither facility can achieve the maximum due to inherent design limitations.

Hallwood-Cordua Fish Screen

The Hallwood-Cordua fish screen is located next to the Yuba River approximately 19 km (12 mi) east of Marysville. The diversion has a capacity of about 17 m^3/s (600 ft^3/s). The screen consists of approximately 360 m^2 (3875 ft^2) of aluminum perforated plate with 4.8 mm (3/16 in.) diameter holes on 6.4 mm (1/4 in.) centers. The open area of the screen is 50% and the designed approach velocity is 15.2 cm/s (0.5 ft/s). The screen is arranged in a vertical walled "V" tapering downstream into a 20.3 cm (8 in.) diameter bypass located at the bottom of the screen. No screen leakage was found during our studies, but losses as great as 50% occurred in the system, particularly in the vicinity of the bypass. These losses were attributed to predation (Hall 1979).

In an attempt to reduce predation losses, the bypass was modified to provide a straight, smooth transition to the exit pipe. This strategy proved effective, reducing losses by about 5% (Kano, MSb). We also constructed a trashrack structure upstream of the screen and documented predation losses associated with the new structure which were as high as 20% (Kano, MSb).

Screen Opening Size

Determination of appropriate hole size to exclude fish from the Peripheral Canal is the result of a threefold approach; morphometric analyses, laboratory experimentation, and data collected from facility evaluations.

Morphometric data including body depth, head width, and fork length were collected for chinook salmon, American shad, striped bass, and white sturgeon. These data, coupled with results of laboratory experimentation allow us to predict the effectiveness of various screen opening sizes.

Fisher (1978) evaluated the retention capabilities of various hole diameters in perforated plate material and mesh sizes of woven wire screen material. Juvenile chinook salmon, striped bass, and American shad were tested at several velocities. He concluded that 3.96 mm (5/32 in.) hole diameter perforated plate and 3.35 mm (1/8 in.) square hole woven wire screen were adequate to exclude chinook salmon larger than 32 mm (1.3 in.), striped bass greater than 20 mm (0.8 in.), and American shad greater than 23 mm (0.9 in.).

Subsequent testing with welded wedge-wire screen material indicated 2.38 mm (3/32 in.) slot width would exclude chinook salmon greater than 30 mm (1.2 in.) and American shad greater than 26 mm (1 in.) (Kano, MSa). This change in opening size is due to a change in the controlling dimension of the fish.

Juvenile white sturgeon in numbers sufficient to conduct tests became available to us for the first time in 1980. Retention tests with an approach velocity of 6 cm/sec (0.2 ft/sec) indicated 3.96 mm (5/32 in.) perforated plate would exclude juvenile sturgeon greater than 26 mm (1 in.) and 2.38 mm (3/32 in.) welded wedge-wire screen would exclude sturgeon greater than 24 mm (0.9 in.). At higher velocities impingement and mortality was too great to permit determinations of screen retention (Reading 1982a).

Approach Velocity

The desired approach velocity is a function of the fishes' swimming ability over a period of time. The size of the screen system proposed for the Peripheral Canal requires a low approach velocity so fish can traverse the length of the screen without being impinged. Swimming ability is related directly to fish size and inversely with water velocity. Since the Peripheral Canal fish screen would have been a "positive-barrier" and a "passive" fish screen (without handling), the approach velocity was established as the velocity at which virtually no impingement takes place.

Chinook Salmon

While determining the impingement tolerance of various fish to assess the feasibility of horizontal traveling screens, Sasaki, Heubach, and Skinner (1972) made the following observations with 6 min tests. The highest velocity at which 90% of 47 to 56 mm (1.9 to 2.2 in.) FL chinook salmon could swim for 6 min. was 21.3 cm/s (0.7 ft/s). The swimming performance of chinook salmon 36 to 38 mm (1.4 to 1.5 in.) FL decreased as velocity exceeded 12.2 cm/s (0.4 ft/s).

Fisher (1981) evaluated the swimming performance of juvenile chinook salmon in longer tests at velocities of 6.1-30.5 cm/s (0.2-1.0 ft/s) during daylight and dark conditions. The tests lasted 6 h with observations made every 0.5 h. He concluded that juvenile chinook salmon should not be exposed for long periods to velocities greater than 12.2 cm/s (0.4 ft/s) and definite impingement occurred at 18.3 cm/s (0.6 ft/s). A summary of the results of this work are presented in Figure 18 and were consistent with other experimental results reported in the literature.

Further studies were conducted subjecting juvenile chinook salmon to 2-vector flow (velocity approaching and velocity passing the screen) conditions against both a vertical screen and a screen sloped away from the channel at 45°. Tests were conducted during daylight and dark conditions with approach velocities up to 10.7 cm/s (0.35 ft/s) and passing velocities (parallel to the screen) up to 28.9 cm/s (0.95 ft/s) (Kano 1982). Over 94% of the chinook salmon averaging 48 mm (1.9 in.) FL were swimming at the end of the 6 h tests with the vertical screen in both light and dark conditions. Over 90% of the fish were swimming in the 6 h tests with chinook salmon averaging 54 mm (2.1 in.) FL and the sloping screen. The poorest swimming ability was observed during dark tests (Kano 1982) (Figure 19).

Striped Bass

Sasaki, Heubach, and Skinner (1972) conducted 6 min tests with 10-50 mm (0.4-2.0 in.) striped bass. The 10-15 mm (0.4 to 0.6 in.) fish were impinged at velocities as low as 12.2 cm/s (0.4 ft/s). Velocities as high as 76.2 cm/s (2.5 ft/s) were required to impinge the largest fish tested.

American Shad

Fisher (1976a) conducted 6 min swimming ability tests on juvenile American shad 30-70 mm (1.2-2.8 in.) FL. He found that velocities in excess of 45 cm/s (approximately 1.5 ft/s) for 6 min tests resulted in substantial impingement and resulting mortality.

Long term (6 h) swimming ability tests were also conducted with American shad (Fisher 1981). Results of these studies indicated juvenile fish are relatively strong swimmers and during the daylight tests the shad survived velocities as high as 24.4 cm/s (0.8 ft/s). In the dark however, mortalities as high as 30% were recorded at velocities of 6.1 cm/s (0.2 ft/s). At 30.5 cm/s (1.0 ft/s), the mortality rose to 80%. The mortalities occurred during the first half hour, thus test duration was not a significant variable during dark tests (Fisher 1981).

When exposed to the 2-vector flow condition tests, juvenile American shad again performed well during daylight conditions for 6 h tests with both

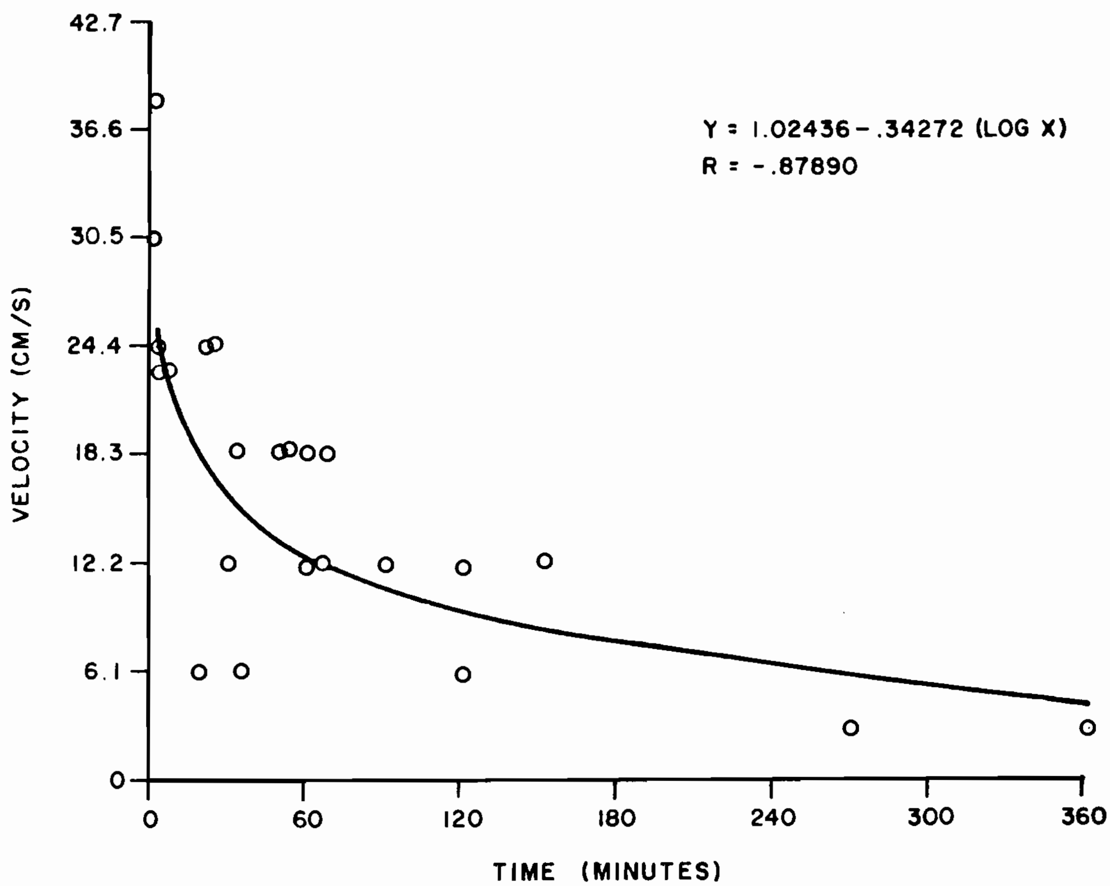


FIGURE 18. Swimming Endurance of King Salmon (32.0 - 41.9 mm fork length) at a 95% Confidence Level (from Fisher, et al 1976)

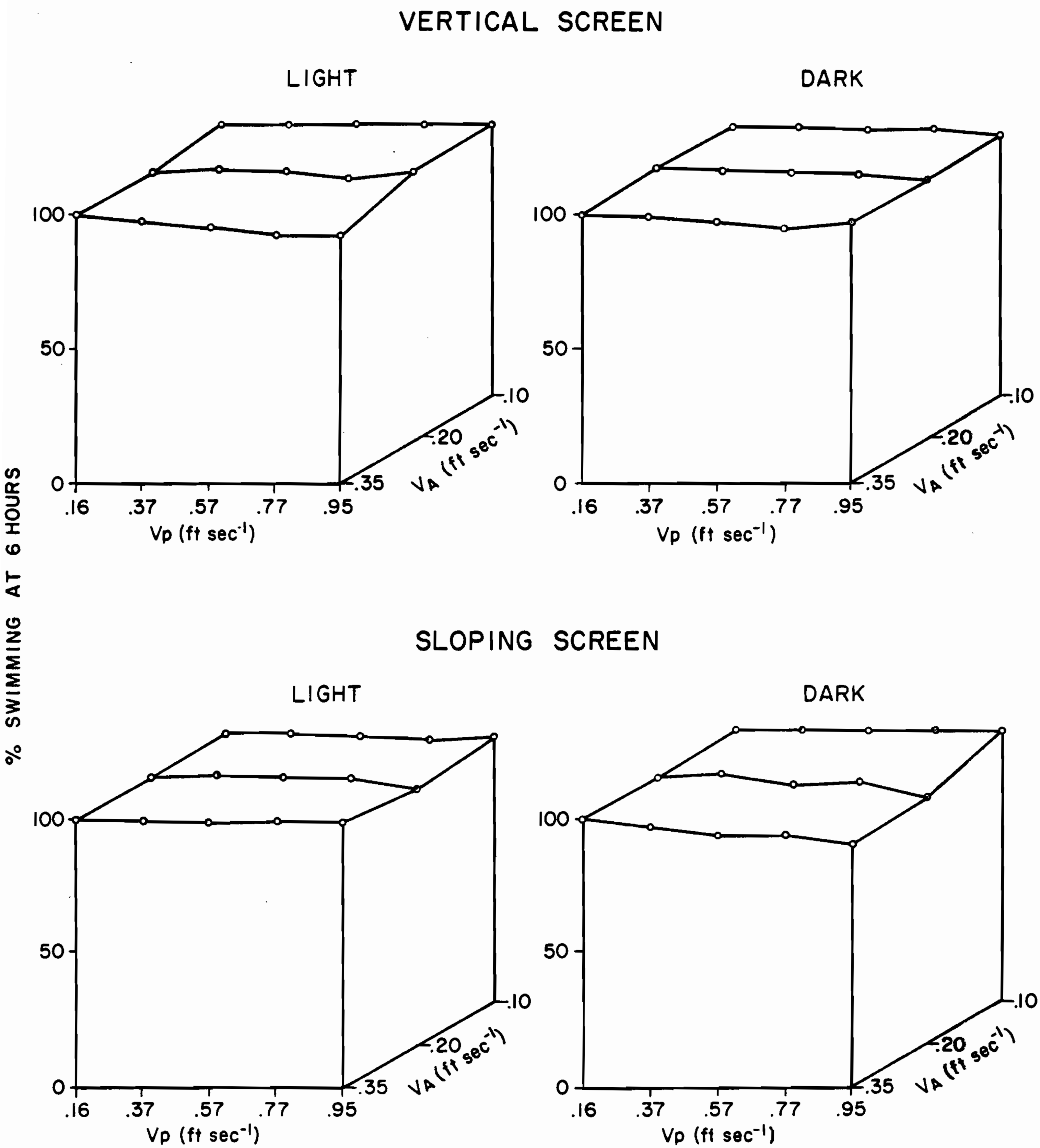


FIGURE 19. Swimming Ability of Chinook Salmon in Relation to Velocities Approaching (V_A) and Passing (V_P) Vertical and Sloping Screen Orientations, Under Light and Dark Conditions (from Kano, 1982)

vertical and sloping screens. During tests conducted in dark conditions, swimming performance dropped to 35% with an approach velocity of 10.7 cm/s (0.35 ft/s) and a passing velocity of 28.9 cm/s (0.95 ft/s) for a vertical screen. These velocities resulted in 0% swimming with the sloping screen. Swimming performance was poor for all velocity combinations with the sloping screen in dark conditions (Kano 1982) (Figure 20).

In an effort to determine when the swimming failure took place during the 6 h tests, a series of tests were conducted with durations from 0.75 h to 6 h with the vertical and sloping screens in the darkness. Twenty-four h mortality for 0.75 h tests ranged from 8.5% with an approach velocity of 6.1 cm/s (0.2 ft/s) to 45% with an approach velocity of 10.7 cm/s (0.35 ft/s) for the vertical screen. Twenty-four h mortalities with the sloping screen were 37% and 84%, respectively (DFG, unpub.).

Sturgeon

Although no swimming ability tests were conducted with sturgeon, the following observations were made during our retention tests. At 6.1 cm/s (0.2 ft/s), impingement averaged as high as 24% for sturgeon averaging 31.3 mm (1.2 in.) in length. At 12.2 cm/s (0.4 ft/s) impingement averaged as high as 66% for sturgeon averaging 34 mm (1.3 in.) and at 18.3 cm/s (0.6 ft/s), 100% impingement was experienced immediately (Reading 1982a).

Bypass Design

Mecum (1980) reported the results of testing various guidance angles, channel velocities, and bypass widths and their effects on bypass efficiencies for juvenile American shad and striped bass. He concluded the bypass width was the most influential variable for American shad. The highest bypass efficiencies were obtained with the widest bypass, 91.5 cm (36 in.). At narrower widths, velocities greater than 61 cm/s (2.0 ft/s) were required to achieve high bypass efficiencies. Bypass efficiency was observed to increase as guidance angle decreased.

Guidance angle and channel velocity were the most important determinants of bypass efficiency for striped bass. A guidance angle of 9.5° and channel velocities greater than 45 cm/s (1.5 ft/s) yielded the highest bypass efficiencies (Mecum 1980).

Mecum (1980) includes a review of available literature on bypass configurations. Results reported in the literature parallel those observed by Mecum. Bypass efficiencies for salmon increased greatly as bypass width increased to about 91 cm (3 ft). Most studies of guidance angle were directed to the effects of the angle of the screen with respect to the flow of water toward the bypass. Results consistently support that guidance angles of 11° or less yield the greatest bypass efficiency (Ruggles and Ryan 1964; Brett and Alderdice 1980).

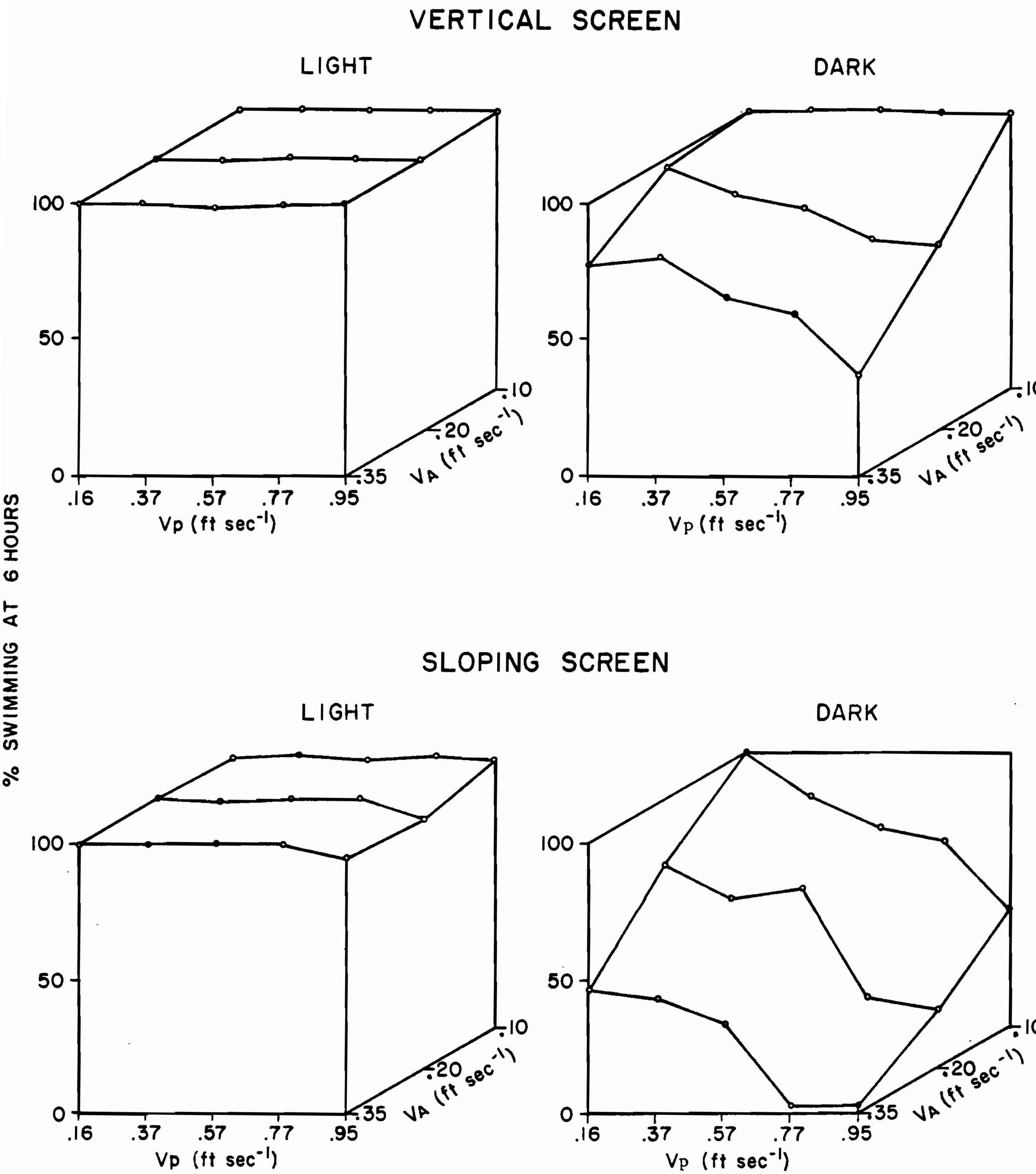


FIGURE 20. Swimming Ability of American Shad in Relation to Velocities Approaching (V_A) and Passing (V_p) Vertical and Sloping Screen Orientations, Under Light and Dark Conditions (from Kano, 1982)

Bypass velocity can be expressed as a velocity or as a ratio of bypass velocity to channel velocity. The ratio is called the bypass acceleration ratio (BAR). Meinz (1978a) reported a 26% increase in bypass efficiency for juvenile chinook salmon in a louver array when the BAR increased from 1.0 to 2.2, with bypass widths of 15.2 cm (6 in.) and 30.5 cm (12 in.). Studies at the Tracy Fish Collection Facility indicated bypass efficiency for striped bass and white catfish increased when the BAR increased from 1.0 to 1.4, with bypass width of 15.2 cm (6 in.) (Bates, Logan, and Pesonen 1960).

Modifications to the bypass at the Hallwood-Cordua fish screen (described earlier) increased the BAR, however we did not measure the velocities. The new alignment and higher BAR resulted in approximately 5% higher recovery rates of marked juvenile chinook salmon (Kano, MSb).

While developing pump concepts, we found that a bypass velocity of at least 46 cm/s (1.5 ft/s) would be required to pass chinook salmon and American shad through a 107 cm (42 in.) fan pump during darkness, and 58 cm/s (1.9 ft/s) would be required during daylight (DFG, unpub.).

Trashracks

The trashrack structures at several existing facilities in northern California evaluated during these studies are responsible for substantial delay and behavioral responses that either directly or indirectly contribute to additional stress and predation (Decoto 1978; Hall 1979, 1980a; Kano MSb). In the past, trashrack bar spacing has been selected to prevent debris from entering the facilities and little or no regard has been given to fish that must negotiate the trashracks.

Juvenile chinook salmon responses to various trashrack bar spacings were investigated in a laboratory situation at U. C. Davis (Hanson and Li, MS). They concluded that trashrack spacings less than 15.2 cm (6 in.) may act as a behavioral barrier for juvenile salmon. They also found that no further gains in passage through the trashrack were achieved with bar spacings greater than 23 cm (9 in.).

Additional testing was conducted at the Hood Test Facility (Reading 1982b). Juvenile American shad and chinook salmon responses to trashrack spacings from 7.6 to 30.5 cm (3 to 12 in.) and velocities from 30.5 to 91.4 cm/s (1 to 3 ft/s) were evaluated. Velocity appears to be the most significant variable controlling passage through the trashracks, with 61 cm/s (2 ft/s) required to pass juvenile shad and salmon. Like Hanson and Li, Reading found 23 cm (9 in.) to be the bar space where passage was maximized.

To gain more information on biological criteria for trashracks, we conducted predation experiments at the Hallwood-Cordua fish screen (Kano MSb). In 1980, we found that the installation of a trashrack with 15.2 cm (6 in.) bar spacing increased predation to as much as 20%. In 1981, we found that enlarging the bar space of the trashrack from 15.2 cm to 30.5 cm (6 in. to 12 in.) reduced predation losses from 23% to 12% in the daytime and 17% to 7% at night.

Fish Pumps

Experiments were conducted in 1967 (Painter, DFG unpub.) to determine the effects of pressure and rapid decompression on threadfin shad, striped bass, Sacramento blackfish, and chinook salmon. Painter concluded that pressures up to 14 kgs/cm^2 (200 psi) followed by rapid decompression did not cause a significantly higher mortality than observed in the controls.

Robinson (1971) reported no significant mortality was experienced for 46-125 mm (1.8-4.9 in.) FL chinook salmon when passed through a 15.2 cm (6 in.) volute (bladeless impeller) pump at up to 900 rpm. He did report that the fish swam erratically and appeared to be disoriented after passing through the pump.

Meinz (1978b) conducted experiments with passing juvenile chinook salmon and American shad through a 15.2 cm (6 in.) volute pump. He concluded that no significant immediate or delayed mortalities were experienced with chinook salmon from 34 to 112 mm (1.3 to 4.4 in.) pumped at 550 and 700 rpm. Mortality attributed to pumping 32 to 87 mm (1.2 to 3.4 in.) American shad at 700 rpm was about 7%. However, he also noted the pumped fish appeared to be disoriented.

Hanson and Mecum (1980) reported on laboratory experiments on the feasibility of a paddlewheel for pumping juvenile salmon. They concluded that the presence of the rotating paddlewheel significantly altered the rheotaxic orientation of juvenile salmon, however no delay in passage was detected. Velocity appeared to be the most important variable influencing fish passage. Juvenile American shad avoided passage through a rotating paddlewheel (Markmann 1980).

Responses of juvenile American shad and chinook salmon to a 107 cm (42 in.) rotating "fan" pump were evaluated at the Hood Test Facility. Fan speed varied from 50 to 120 rpm and channel velocities tested were 15.2, 30.5, 45.7, and 57.9 cm/s (0.5, 1.0, 1.5, and 2.0 ft/s) (DFG, unpub.). Preliminary results indicate the pump did not cause significant mortality for juvenile American shad or salmon. A significant delay or avoidance was experienced particularly with American shad during dark tests with the pump running until velocities in excess of 45.7 cm/s (1.5 ft/s) were tested. Additional studies are underway in a larger flume to further develop the biological criteria for a bypass pump.

Fish Return System

Reports summarizing problems expected in a fish return system have been prepared (FFTCC 1980b, 1981b). To properly design a fish return system, it is important to consider hydraulic conditions in the Sacramento River during major fish migrations, predator abundance, and behavior, as well as biological criteria that reduce stress on fish returned to the river and conditions within the fish return system.

Predation

The presence of predator populations in and around fish facilities evaluated during these studies was commonly observed (Hall 1977, 1979, 1980a, b; Schaffter 1978). This probably occurs because of physical conditions which are favorable to predators as well as increases in the concentration and/or vulnerability of prey.

Studies were performed at Horseshoe Bend on the lower Sacramento River to compare predator populations at a site where fish collected at CVP and SWP facilities are released versus a control site where no fish were released. Results indicate that striped bass, the most common predator observed, did not congregate around the release site to take advantage of the regular, abundant food supply. Striped bass in the test area at the time of prey release fed at a higher rate than those in the control area. Sacramento squawfish, the second most common predator, concentrated at the release site, as evidenced by their increased residence time in the area (Pickard, Grover, and Hall 1982).

A limited amount of ultrasonic tracking was conducted with striped bass and Sacramento squawfish at the John E. Skinner Delta Fish Protective Facility and the Glenn-Colusa Fish Facility. Information collected during these experiments also suggest that Sacramento squawfish behave as resident predators while striped bass are more transient (Hall 1980b).

Evaluations conducted at Clifton Court Forebay with spray-dyed juvenile hatchery chinook salmon indicate substantial losses are experienced in the forebay. Schaffter (1978) could only account for 3% and Hall (1980a) could only account for 12% of the fish they released at the radial gate entrance to the forebay. In both of these experiments, the mean size of the recovered salmon was significantly greater than the mean size of the fish when they were released. Since trawling and seining efforts in the forebay were unsuccessful in capturing marked salmon, both investigators concluded the losses were due to predation, probably by striped bass, with mortality rate being inversely related to prey size.

Predation experiments were also conducted at the Hallwood-Cordua fish screen. Hall (1979) determined that predation by Sacramento squawfish was significantly greater at the screen face than in the channel upstream from the screen. Kano (MSb) confirmed Hall's results and documented losses as high as 20% associated with a trashrack structure. Kano also determined that predation losses could be reduced by making "improvements" in the bypass of the fish screen.

Based on these and other similar studies, we have concluded that the most important potential predators at fish facilities on the lower Sacramento River will be striped bass, Sacramento squawfish, and downstream migrant juvenile steelhead (Pickard, Grover, and Hall 1982).

We also conducted an extensive literature search to help us formulate plans for managing predation. The results of this search were reported earlier (FFTCC 1980b) and are summarized below.

Increased predation will occur wherever small fish are delayed, concentrated, and/or stressed. The literature does not explicitly state what levels of stress and concentration will stimulate predation.

The literature offers some assistance for minimizing and discouraging predation at the intakes and fish facilities. Piers, pilings, other supportive structures, and corners or other irregularities in a channel are referred to as structural complexities. Such structures may cause uneven flows and can create shadows and turbulent conditions. A structurally complex environment should be avoided. Corners, interstices, or other structural components that create boundary edges contribute to maximum foraging efficiency of large predatory fishes and the highest populations of predators will occur where structural boundary edges are present. Structural complexity can increase predation by providing locations for waiting predators (shadows, interstices, corners, etc.). The risk of prey to predation is a function of exposure, often directly related to the structural complexity of the system. Because the species of primary concern as potential prey in the lower Sacramento River (chinook salmon, American shad, striped bass) are primarily schooling species as juveniles, increasing structural complexity could delay their passage along the screen. Exposure to predation for these species is best reduced by school formation and utilization of escape mechanisms such as darting and scattering.

Engineering design should provide smooth flow patterns with a minimum of eddies, flow shears, or abrupt changes in velocity. Ideally, flow past the screen should be unidirectional with a positive downstream flow under all tide and flow conditions. The bypass exit should be located sufficiently downstream to prevent repeated exposure to the screens, while at the same time considering the relative effect of bypass channel lengths.

The report also includes a discussion of techniques to manage predator populations should they develop after the facility is in operation (FFTCC 1980b).

Adult Migrants

The facility must provide for the passage of adult upstream and downstream migrants passing the proposed intake. Upstream migrating adults including chinook salmon, striped bass, steelhead rainbow trout, American shad, and sturgeon must be able to migrate past the intake without significant delay or mortality. Downstream migrating adults, including striped bass, American shad, steelhead rainbow trout, and sturgeon must also be able to move past the intake successfully. These downstream migrant fish, weakened by their spawning migration, may present a serious problem for the design of the facility.

ENGINEERING STUDIES

The engineering studies were conducted by the staff of DWR. Two efforts proceeded concurrently. The first, preliminary design and hydraulic model studies, was a Division of Design and Construction effort. The second, clogging, cleaning, and corrosion studies, was a planning effort under the Central District Office.

Hydraulic Model Studies

The DWR's Division of Design and Construction provides design engineering support to the Fish Facilities Program. One aspect of that support has been to develop alternative diversion schemes for various preliminary design fish screen configurations, and for ancillary facilities such as flood control features and return channels based on the results of the various testing programs. Other support has included contracting with the Department of Land, Air, and Water Resources, University of California (Davis) for the development, construction, and testing of mathematical and physical models of the Sacramento River and alternative intake system configurations for the Peripheral Canal.

General

Three models have been developed at Davis over the years; one mathematical and two physical. Initially, a mathematical model was developed for the reach of the Sacramento River between Snodgrass Slough and the City of Sacramento (Bamgboye et al. 1981). The mathematical model provides the basis for evaluating and adjusting the physical models. The first physical model of the Sacramento River near Hood, including the intake, was a model of about 8.4 km (5.2 mi) of the river. A distorted scale model (horizontal 1:240, vertical 1:60) was necessary to obtain sufficient depth of flow in the model channel to conduct studies of velocities and bedload sediment movement in the vicinity of the proposed intake. The 1:240 model had a bed composed of specially ground walnut shell flour which permitted some qualitative evaluation of bedload movement. The results of the 1:240 model studies have been thoroughly described by Hartman et al. (1979) and are only briefly highlighted below. The second physical model at the Davis Campus is an undistorted 1:50 model of 3.4 km (2.1 miles) of the Sacramento River near Hood. The purpose of this large model was to evaluate hydraulic characteristics of alternative intake configurations, trashrack systems, fish screens, and channel alignments to provide information on flow patterns in the river at the canal intake and in the intake channel itself.

The 1:240 Model

A schematic diagram of the 1:240 model is shown in Figure 21. Water surface gradients in the model were made to match those of the mathematical

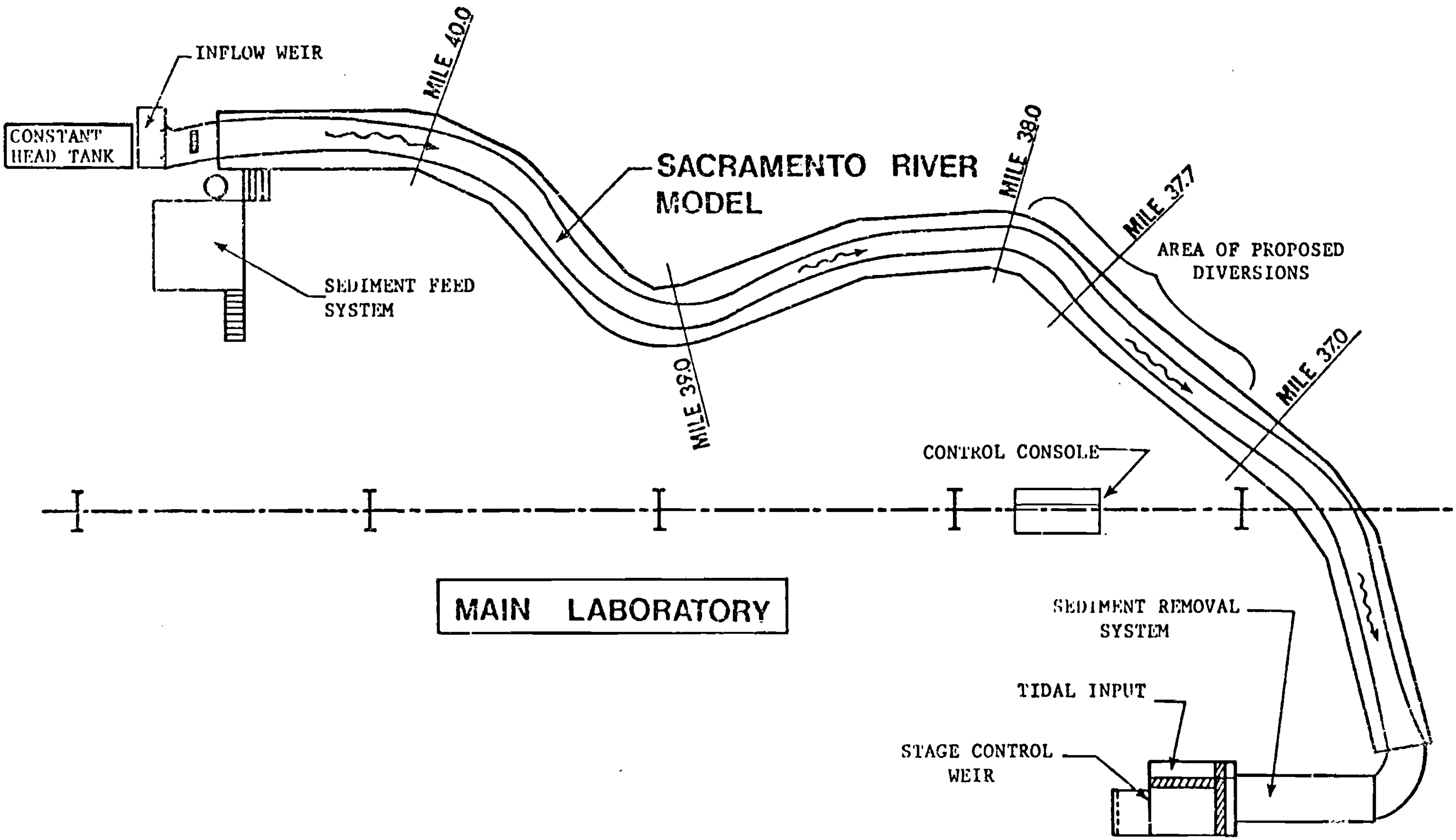


FIGURE 21. General model layout; 1:240 model (from Hartman, et al., 1979)

model by the installation of roughness elements (chicken wire and hardware cloth) on the sides of the model. Cross-sections of the river, taken by DWR at approximately 305 m (1000 ft) intervals during a four-month period (December, 1974-April, 1975) were used to design and calibrate the model without the proposed turnout. The cross-section templates were also used to determine changes in distribution of sediment on the bed after various diversion formats had been tested.

The diversion formats tested in the 1:240 model included the following conditions:

1. Screens located either on-river or off-river. In both cases, the screens were of the plate along one bank type. No attempt was made to model the screens themselves; however, diversion flows projected to go through areas where the screens would be in the prototype were modeled.

2. Five diversion operating conditions:

Condition	River flow m^3sec^{-1}	River flow (ft^3sec^{-1})	Diversion m^3sec^{-1}	Diversion (ft^3sec^{-1})
a	2832	(100,000)	453	(16,000)
b	1048	(37,000)	433	(15,300)
c	705	(24,900)	660	(23,300)
d	368	(13,000)	326	(11,500)
e	176	(6,200)	142	(5,000)

   With prototype river flows in the above range, model river flows ranged from 0.002 to 0.026 m^3sec^{-1} (0.06 to 0.90 ft^3sec^{-1}).

3. Approach velocities of 6.1 and 12.2 cm/s (0.2 and 0.4 ft/s). These velocities were given, and the screen area determined by dividing the diversion flow by the approach velocity.

Because of scale distortion, the 1:240 model only provided qualitative information on what could be expected in the prorotype as a result of diversions into the Peripheral Canal. The most significant model result, in terms of designing an intake for the Peripheral Canal, involved the apparent buildup of sediment in front of the fish screen (especially the lower one-third) in the on-river scenario. During many flow conditions with the on-river design, significant amounts of bedload were diverted into the fish screen structure. In the off-river concept, sediment problems were minimized by adjusting the location of the intake structure at the bend in the river.

The 1:50 Model

The 1:50 model is an undistorted representation of a 3.4 km (2.1 mi) segment of the Sacramento River near Hood, and includes a channel for the off-river concept for the fish protection facility. A schematic diagram of the model is shown in Figure 22. The bed in this model is sand, and is considered unmovable at the model velocities tested. The model can be modified to test a movable bed if needed.

Testing with the 1:50 model was not completed and available data is being evaluated and a report is being prepared. Model verification consisted of comparing velocity measurements in the model (prior to the installation of the diversion) with the measurements made in the river as described in the 1:240 model section. The results indicated very good reproduction of the flow patterns measured in the river for both velocity and direction of flow.

Testing began with a 305 m (1000 ft) wide turnout structure and 30.5 cm/s (1.0 ft/s) velocity in the off-river channel. Prior to the completion of this series, a decision to change to a 152 m (500 ft) turnout with a channel velocity of 61 to 90.5 cm/s (2 to 3 ft/s) resulted in the completion of a modified testing program. A preliminary report was prepared which documented the presence of excessive eddies and objectionable flow patterns for the 305 m (1000 ft) opening configuration tested (DeVries et al. 1981).

Testing with the 152 m (500 ft) opening with a 61 cm/s (2 ft/s) velocity in the off-river channel and the "plate along one bank" screen has been completed (Amorocho et al. 1982). Efforts were made to reduce the objectionable eddies and flow patterns and the indications are that a solution can be reached for one set of diversion and river flow conditions. Changes in these conditions introduce eddies, and attempts to resolve this problem were being considered when a decision to concentrate on staging of the construction was made. Future efforts will center on staged construction designs utilizing the preliminary design criteria (FFTCC 1981b).

Clogging, Cleaning, and Corrosion Studies

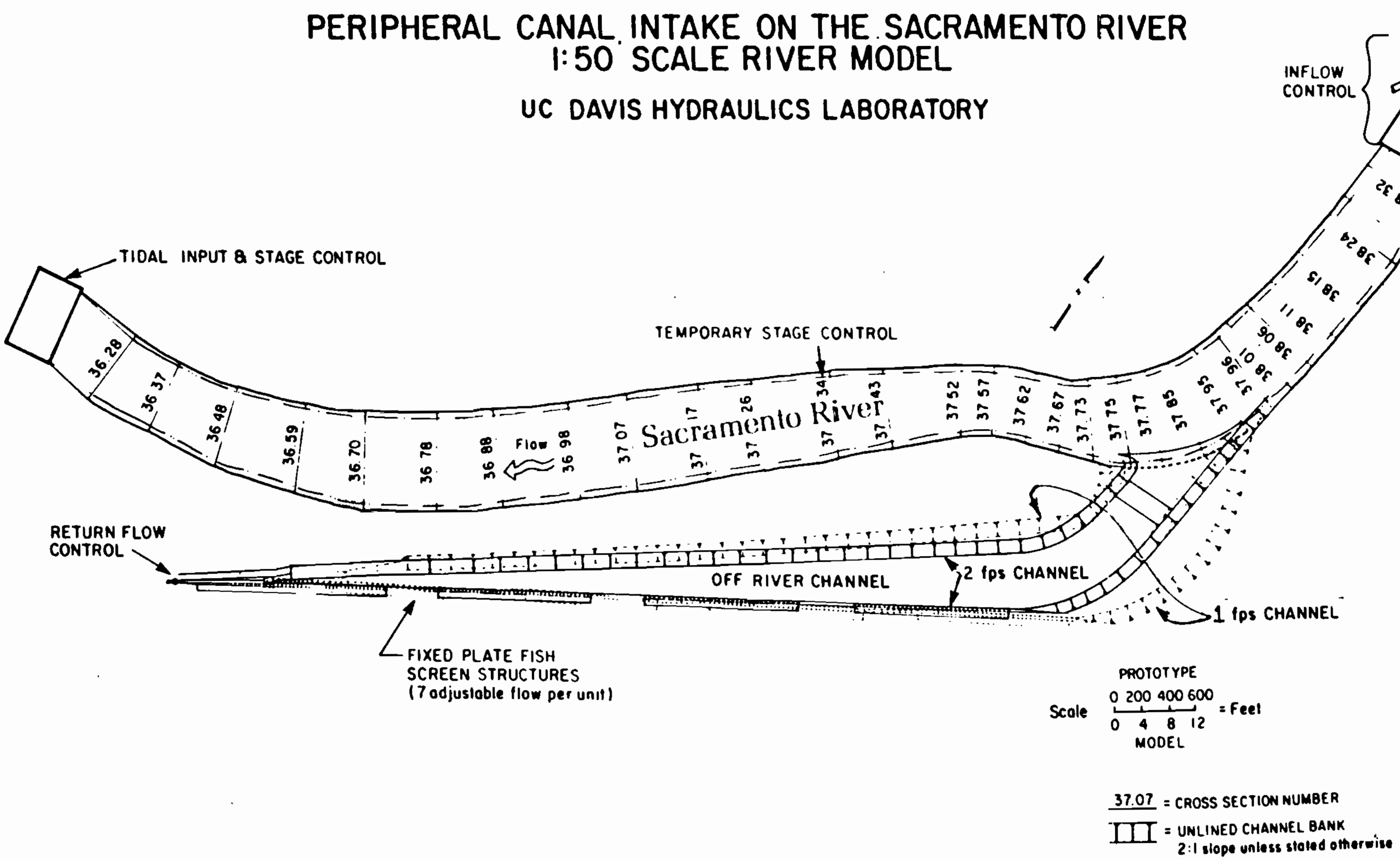
In the early 1970's, when a positive barrier screen concept was adopted, the DWR began design of a facility to determine clogging rates of various screen materials, evaluate cleaning techniques, and determine the corrosion rates of materials that might be used to construct the screens. The test facilities were constructed at Hood and data collection began in 1975. Except for a shutdown during the 1976-77 drought (the water supply pumps were needed elsewhere), data collection continued through 1980. The results of this work have been described by Smith and Ferguson (1979) and Smith (1982).

The general objectives of the study were to:

1. Gather data on the suspended material (debris) that would cause the fish screens to clog. The information would be such that clogging potential of the debris could be related to flow.

2. Determine the potential of Sacramento River water near Hood to support periphytic and other attached aquatic growth which would clog the fish screens.

FIGURE 22.


PERIPHERAL CANAL INTAKE ON THE SACRAMENTO RIVER
1:50 SCALE RIVER MODEL
UC DAVIS HYDRAULICS LABORATORY
INFLOW CONTROL
TIDAL INPUT & STAGE CONTROL
TEMPORARY STAGE CONTROL
Sacramento River
Flow
36.28
36.37
36.48
36.59
36.70
36.78
36.88
36.98
37.07
37.52
37.57
37.62
37.67
37.73
37.75
37.77
37.85
37.95
37.96
38.01
38.06
38.11
38.15
38.24
38.32
RETURN FLOW CONTROL
OFF RIVER CHANNEL
2 fps CHANNEL
1 fps CHANNEL
FIXED PLATE FISH SCREEN STRUCTURES (7 adjustable flow per unit)
PROTOTYPE
Scale
0 200 400 600 = Feet
0 4 8 12
MODEL
37.07 = CROSS SECTION NUMBER
= UNLINED CHANNEL BANK
2:1 slope unless stated otherwise

3. Determine the rates at which various configurations of screen materials clog under debris and aquatic growth conditions found in the Sacramento River near the site of the proposed Peripheral Canal intake.

4. Evaluate the combined effect of varying combinations of approach velocity, debris concentration, and aquatic growth on screen clogging.

5. Determine the most effective means of keeping the headloss across the face of the screens below an acceptable level.

6. Determine the corrosion rate (rate of loss of material from screens suspended in water) of materials that were likely candidates for screen construction.

7. Determine the overall feasibility of keeping the screens in a fish protection facility sufficiently clean so that headloss across the screens and nonuniform through-hole velocities caused by localized clogging were not problems.

Experimental Methods

The interested reader can refer to reports cited earlier for detailed description of the study methods. The following serves to provide a general understanding of the techniques used.

Debris Studies - In this study, debris is defined empirically as that material retained in a net with nominal mesh openings of 500 micrometers. The debris collected included planktonic algae, detrital material, leaves, small sticks, sediment, etc. Debris estimates in the river were obtained using nets at nine locations in a transect near Hood, covering the horizontal and vertical profiles. The samples were taken approximately two times per month over a period of several years and thus represent the range of debris conditions expected in the river. Similar samples were collected in the test flume to assure ourselves that the conditions in the flumes were representative of those in the river. Analysis of samples included a qualitative determination of the major components of the debris, as well as dry weight and ash dry weight.

Aquatic Growth Studies - Aquatic growth was measured on sections of test screens with 3.96 mm (5/32 in.) holes on 5.56 mm (7/32 in.) centers submerged in the Sacramento River. Two sites, one on a floating platform near Hood and the second attached to bridge abutments about 9.7 km (6 mi) below Hood were used. The test screens were at depths of 0.9 and 3.0 m (3 and 10 ft) at each site. Water was pumped through the screens at rates which provided approach velocities of either 3.0 or 6.1 cm/s (0.1 or 0.2 ft/s). Accumulation of aquatic growth and trapped debris was measured indirectly by recording changes in headloss across the screens. Samples were also taken for qualitative identification of major components by laboratory technicians.

Larger 1.2 X 3.0 m (4 X 10 ft) test screens used in the clogging and cleaning tests were also monitored for accumulation of periphyton and other aquatic organisms.

Clogging Tests - The clogging and cleaning studies were conducted in flumes at the Hood Test Facility; a schematic diagram of which is shown in Figure 23. The facility consists of a series of flow control structures (flumes, pumps, gates, weirs, bypasses, etc.) designed to move known quantities of water past and through one or more test sections of fish screens. The major controllable test variables in this facility were approach velocity and screen type. Debris concentration was ambient; however, during the four years of tests, practically all combinations of debris, approach velocity, and screen type were experienced. Time to reach a specific headloss across the screen face was the measured dependent variable.

Approach velocities tested ranged from 6.1 to 24.4 cm/s (0.2 to 0.8 ft/s), a range which is expected to cover allowable approach velocities in Peripheral Canal fish screens.

Types of screens tested are listed in Table 4. Study emphasis was on perforated plate and profile wire, oriented vertically and parallel to the main direction of flow. A panel of perforated plate, vertical orientation, with 3.96 mm (5/32 in.) openings on 5.56 mm (7/32 in.) centers was always tested and served as a "standard" against which other screen types and orientations were compared.

Most screens tested were in the form of vertical flat plates. Two other screen configurations tested were a flat perforated plate tilted away from the main channel at 45° but still parallel to the main channel ("sloping screen"), and a vertical drum, constructed of profile wire, tested in both the stationary and revolving modes.

Cleaning Tests - Cleaning tests were conducted using screens in the flume of the Hood Test Facility. The two types of cleaning methods tested were brushes (underwater only) and spray (both above and below the water surface). Several types of brushes were tested varying in such elements as the type of material (nylon or polypropylene), bristle diameter (0.6-1.5 mm; 0.022-0.060 in.), length (38-64 mm; 1.5-2.5 in.), and the number of bristles (19-71/cm; 48-180/in.). The brush cleaner was tested on screens 1, 2, 3, 7, and 12 listed in Table 4.

Variables tested with the brush cleaner were:

Screens	3.96 mm (5/32 in.) perforated plate; 2.38 mm (3/32 in.) welded wedge-wire; 2.4 mesh/cm (6 mesh/in.) woven wire; 4.76 mm (3/16 in.) perforated plate; 6.35 mm (1/4 in.) perforated plate
Water Velocity	6 cm/s (0.2 ft/s); 12 cm/s (0.4 ft/s); 18 cm/s (0.6 ft/s); 24 cm/s (0.8 ft/s)
Brush Pressure	4.1 to 7.5 kg/m (2.8 to 5.1 lb/ft)
Brush Travel Speed	15 cm/s (0.5 ft/s); 25 cm/s (0.8 ft/s); 50 cm/s (1.6 ft/s); 75 cm/s (2.5 ft/s)

FIGURE 23. Hood Fish Screen Test Facility (from Smith, 1982)

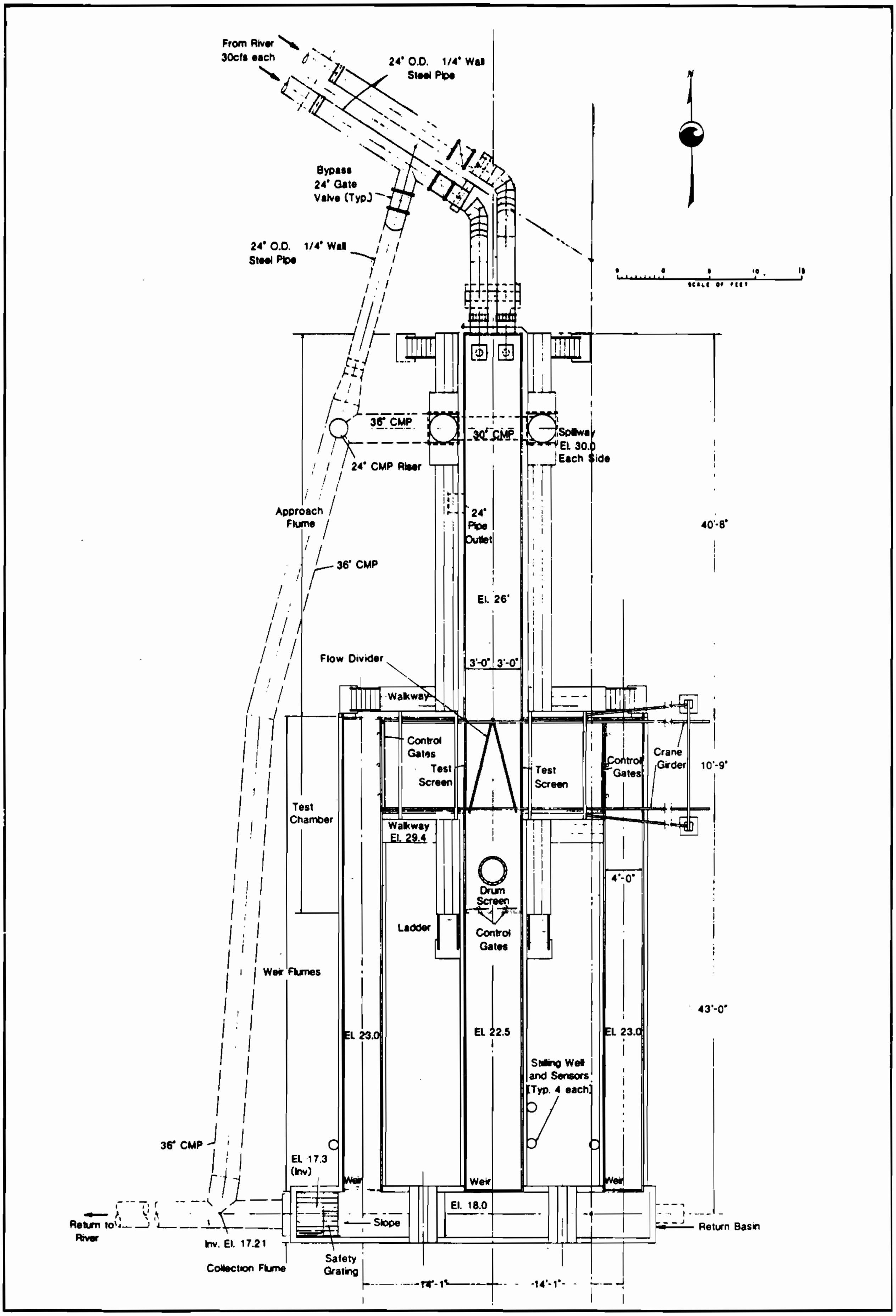


TABLE 4. TEST SCREENS AND SPECIFICATIONS
(from Smith, 1982)

VERTICAL FLAT SCREENS

Perforated Plate (PP)

Screen No.	Material	Hole Diameter (mm)	Plate Thickness (mm)	Staggered Spacing (mm)	Holes Per cm^2	Percent Open Area	Weight Per m^2 (kg)
1	SS-304	4.0	1.5	5.6	3.7	46.2	5.7
2	SS-304	4.8	1.5	6.4	2.8	51.0	6.3
3	SS-304	6.4	1.5	7.9	1.7	58.0	7.1
4	AL-6061-T4	4.0	1.5	5.6	3.7	46.2	2.0
5	(Same as No. 1 with the 63.5 mm standard corrugations)						

Woven Wire Square Mesh (SM)

Screen No.	Material	Mesh Per cm	Wire Diameter (mm)	Opening Width (mm)	Opening Diagonal (mm)	Percent Open Area	Weight Per m^2 (kg)
6	SS-304	2.7	.89	2.7	3.9	57.2	2.8
7	SS-304	2.4	.89	3.4	4.7	62.7	2.3
8	SS-304	1.6	1.60	4.7	6.7	56.0	5.1
9	Polyester	2.4	.99	3.4	4.7	59.0	0.5

Woven Wire Slotted Mesh (Sl M)

Screen No.	Material	Slot Opening (mm)	Wire Diameter (mm)	Percent Open Area	Weight Per m^2 (kg)
10 1/	High Carbon Steel	2.0x13	1.6	50.1	5.8
11 2/	High Carbon Steel	2.5x9.4	1.1	61.2	3.4

Welded Wedge-Wire Slotted Screen (WWW)

Screen No.	Material	Slot Opening (mm)	Wire Thickness (mm)	Percent Open Area	Weight Per m^2 (kg)
12	SS-304	2.4x continuous	2.0	54.0	27.1

SCREENS OF OTHER ORIENTATION OR CONFIGURATION

Perforated Plate (PP)

13 (Same as No. 1 parallel to approaching flow but slanted 45 degrees)

Welded Wedge-Wire Slotted Screen (WWW)

14 (Same as No. 13, fabricated into a 0.9 m diameter drum with vertical axis, stationary)
15 (Same as No. 14, continuously rotating)
16 (Same as No. 12, two fabricated round screens, each 0.6 m in length and diameter, joined together in a "T")

1/ Had a variable thickness coating of an algaecide -- Tributyltin Oxide.

2/ Had a thin coating of a fused epoxy.

Several nozzles were tested that concentrate water impact in a thin band (flat spray nozzles). The output ranged from 28 to 246 liters/min (7 to 65 gal/min) at a pressure of 410 kPa (60 lbs/in.^{2}). The spray bar was tested on screens 1, 2, 3, 5, 7, 10, and 12 listed in Table 4.

Variables tested included:

Variable	Out of Water	Underwater
Wash Pattern	Horizontal, vertical	Horizontal
Washed Surface	Front, back, both	Front, back
Spray Impact Angle	45°, 90°	90°
Nozzle Distance from Screen	25 cm (10 in.); 40 cm (16 in.); 76 cm (30 in.)	2.5 to 38 cm (1 to 15 in.)
Spray Bar Travel Speed	10, 25, & 50 cm/s (0.3, 0.8, & 1.6 ft/s)	25 cm/s (0.8 ft/s)
Spray Bar Pressure	35 to 690 kPa (5 to 100 lbs/in.^{2})	275 to 825 kPa (40 to 120 lbs/in.^{2})

Corrosion Studies - Four racks of samples of different screen materials (including 304, 316, and 347 stainless steel, weathering steel, mild steel, enamel coated steel, and 6061-T4 and 5052-H32 aluminum) were suspended 0.6 to 0.9 m (2 to 3 ft) below the water surface of the Sacramento River near Hood. The samples were weighed before immersion and then one rack of samples was removed at 6, 12, and 18 months after immersion and reweighed. All the samples were reweighed after they had been in the water for about 47 months. The loss of material over time was considered to be a measure of its corrosion potential. Visual observations and photographs were also used to document corrosion effects (pitting, etc.).

Results

The results of the clogging, cleaning, and corrosion studies are summarized below. A full description is available (Smith and Ferguson 1979; Smith 1982).

Debris Concentration - Figure 24 contains a plot of the observed relation between average debris concentration in the river (material collected in a net with a nominal mesh size of 500 micrometers) and river flow, along with an indication of the dominant debris component. Peak concentrations were on the order of 1 mg/l at flows that ranged to 2110 m^3 sec^{-1} (74 x 10^3 ft^3 sec^{-1}). The debris exhibited definite seasonal patterns with large amounts of fibrous, decomposing plant material in the winter-spring period of high flows; relatively smaller amounts of algal and animal material during the summer-fall period of low flows; and abundant leaves with algae or detritus during a few weeks in late fall and early winter.

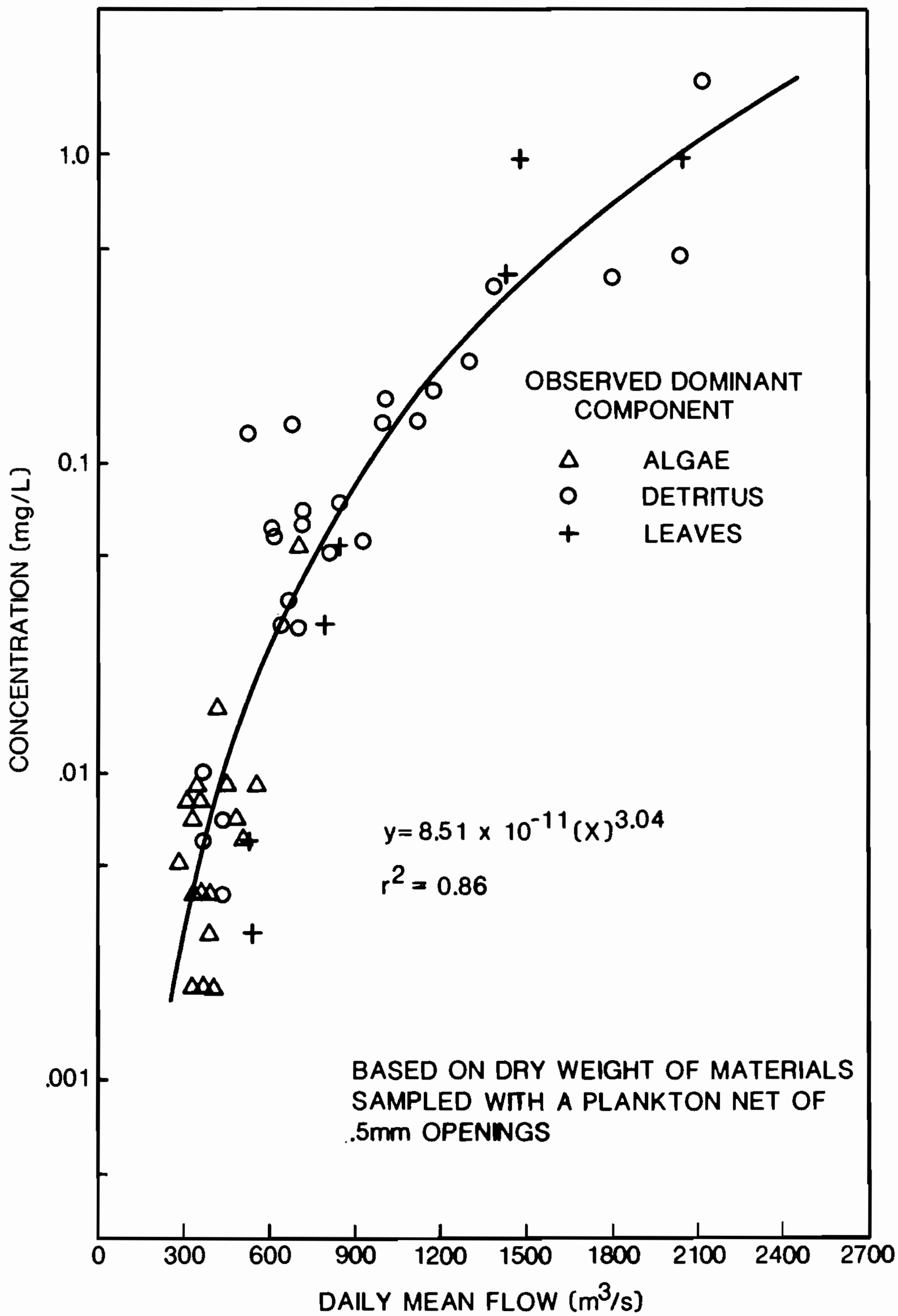


FIGURE 24. Concentration and dominate component of debris sampled in the Sacramento River at Hood 1975 - 1979 (from Smith, 1982)

In terms of applicability of the test results, it was important that the debris concentrations in the test flume approximate those found in the river. The relationships plotted in Figure 25 demonstrate that, for most flows, debris concentrations in the flume were representative of those in the river. At high flows, the debris is less than that in the river, however, even then the differences are not so great as to cause significant bias in the results.

Debris concentrations are only an arbitrary means of identifying something in the water suspected to cause screen clogging. The importance of this type of data lies in its use as a predictor for clogging rates. How well the relationship holds will be shown later in this section.

Aquatic Growth - The aquatic growth studies were hampered by mechanical and electrical problems with the test apparatus. The test screens were colonized by plant and animal forms which is expected when any artificial substrate is submerged in the aquatic environment. The dominant forms colonizing the screens were the diatoms *Melosira*, *Synedra*, and *Fragilaria*, and a green alga of the genus *Spirogyra*. Animal material found included insect larvae, polychaete worms, stalked ciliates, and bryozoans. The organisms in the test canisters suspended in the river were qualitatively the same as those found on test screens in the Hood Test Facility. No tests were conducted in this study of fouling potential of screens containing antifouling metals (copper alloys, for example).

Screen Clogging - The screen clogging data are summarized in Figures 26 and 27. In Figure 26 the amount of accumulated headloss versus time has been plotted for some of the screens tested in the vertical configuration. (The plotted lines are actually a synthesis of a large volume of data into regression lines.) The data have been adjusted (normalized) so that the approach velocity is 6.1 cm/s (0.2 ft/s) and the debris concentration is 0.03 mg/l (0.03 ppm). Based on current information, the approach velocity and debris concentration which would occur at the Peripheral Canal Fish Protection Facility during most of the year would be less.

DFG data on fish retention by various mesh sizes and types indicate that acceptable protection of juvenile American shad, salmon, and striped bass (not eggs and larvae of striped bass) can be achieved with 3.96 mm (5/32 in.) openings in perforated plate and 2.38 mm (3/32 in.) slot width in the welded wedge-wire screens. Using this criterion of acceptable mesh size, the comparison in Figure 26 can be effectively limited to looking at screens meeting these size requirements. It took the 2.38 mm (3/32 in.) welded wedge-wire about 5 times as long to reach 6.1 cm (0.2 ft) of headloss when compared to the 3.96 mm (5/32 in.) perforated plate.

Similar regression lines in Figure 27 can be used to obtain some idea about the effect of screen configuration on clogging rate. The debris concentration and approach velocity have again been normalized to 0.03 mg/l (0.03 ppm) and 6.1 cm/s (0.2 ft/s), respectively. Looking first at the 3.96 mm (5/32 in.) perforated plate, the time to reach 6.1 cm (0.2 ft) on headloss went from about 12 hours in the vertical orientation to about 30 hours when the screen was sloped at an angle of 45°. The vertical plate wedge wire was even more effective than the sloped perforated plate (60 h to reach 6.1 cm [0.2 ft]), and when the wedge wire was made into the form of a vertical drum (cylinder), the time to reach 6.1 cm (0.2 ft) increased to an estimated 140 h.

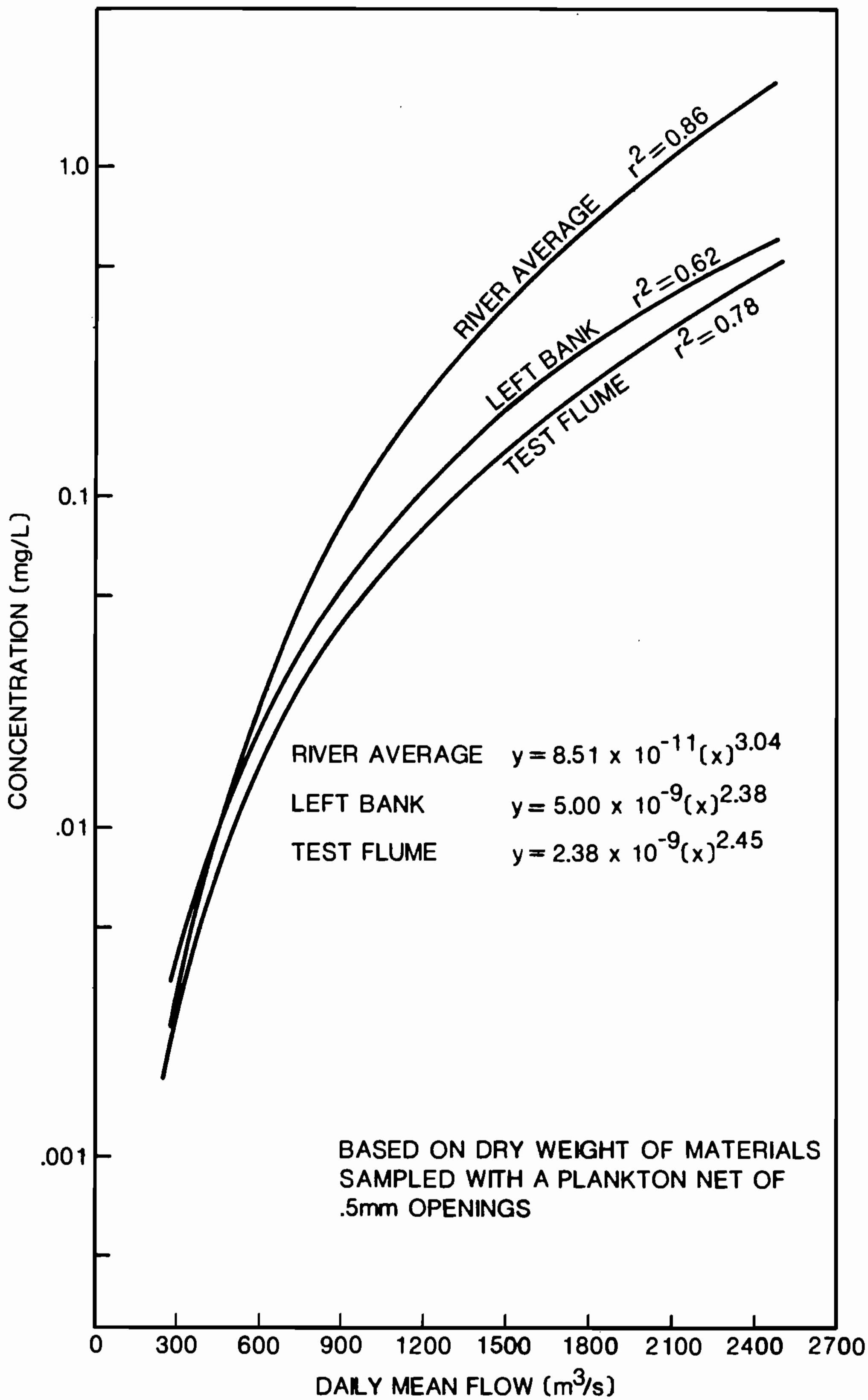


FIGURE 25. Concentration of debris in the Sacramento River at Hood and in the Hood test facility 1976 - 1979 (from Smith, 1982)

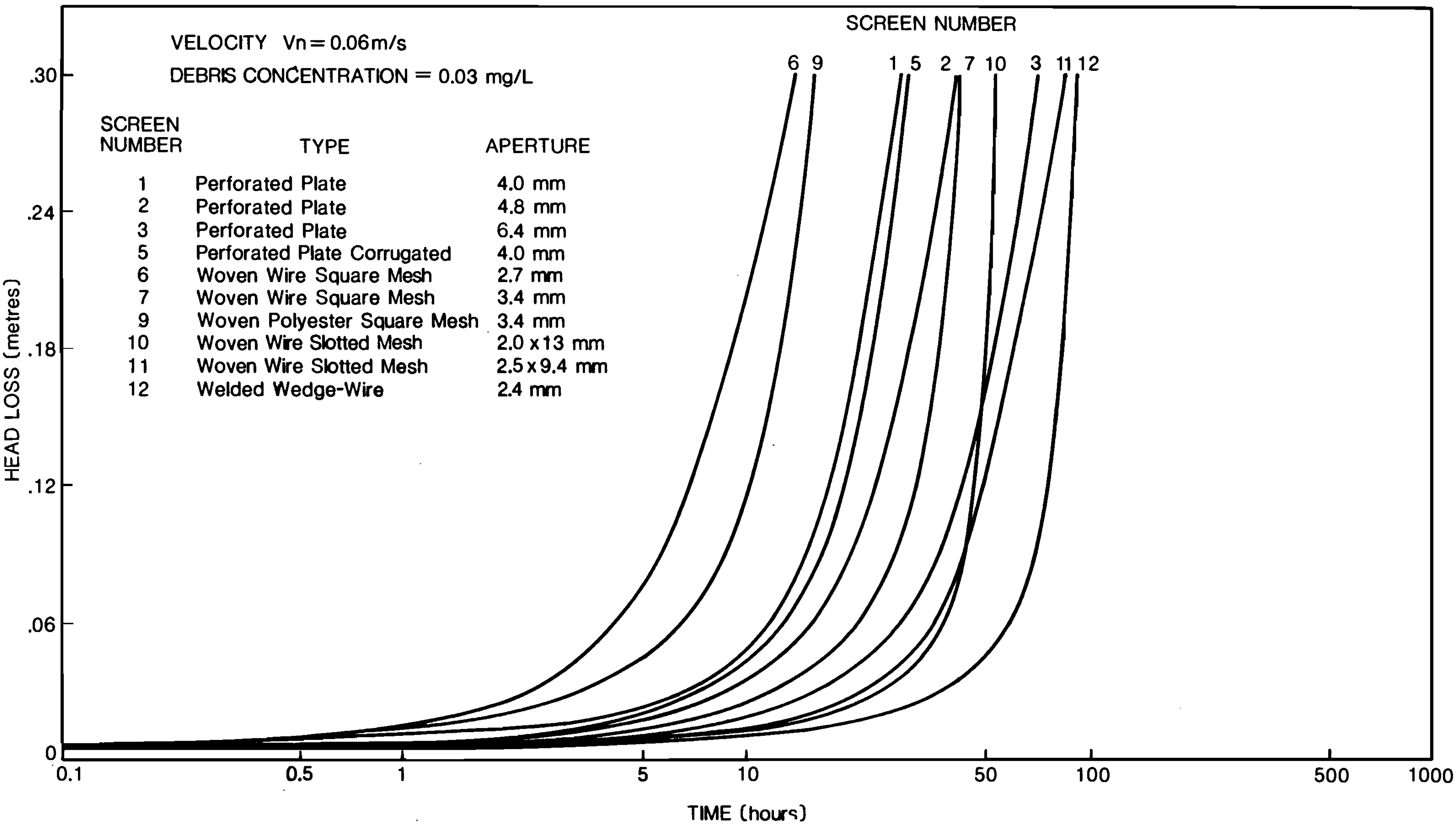


FIGURE 26. Clogging Rates of Vertical Flat Screens (from Smith, 1982)

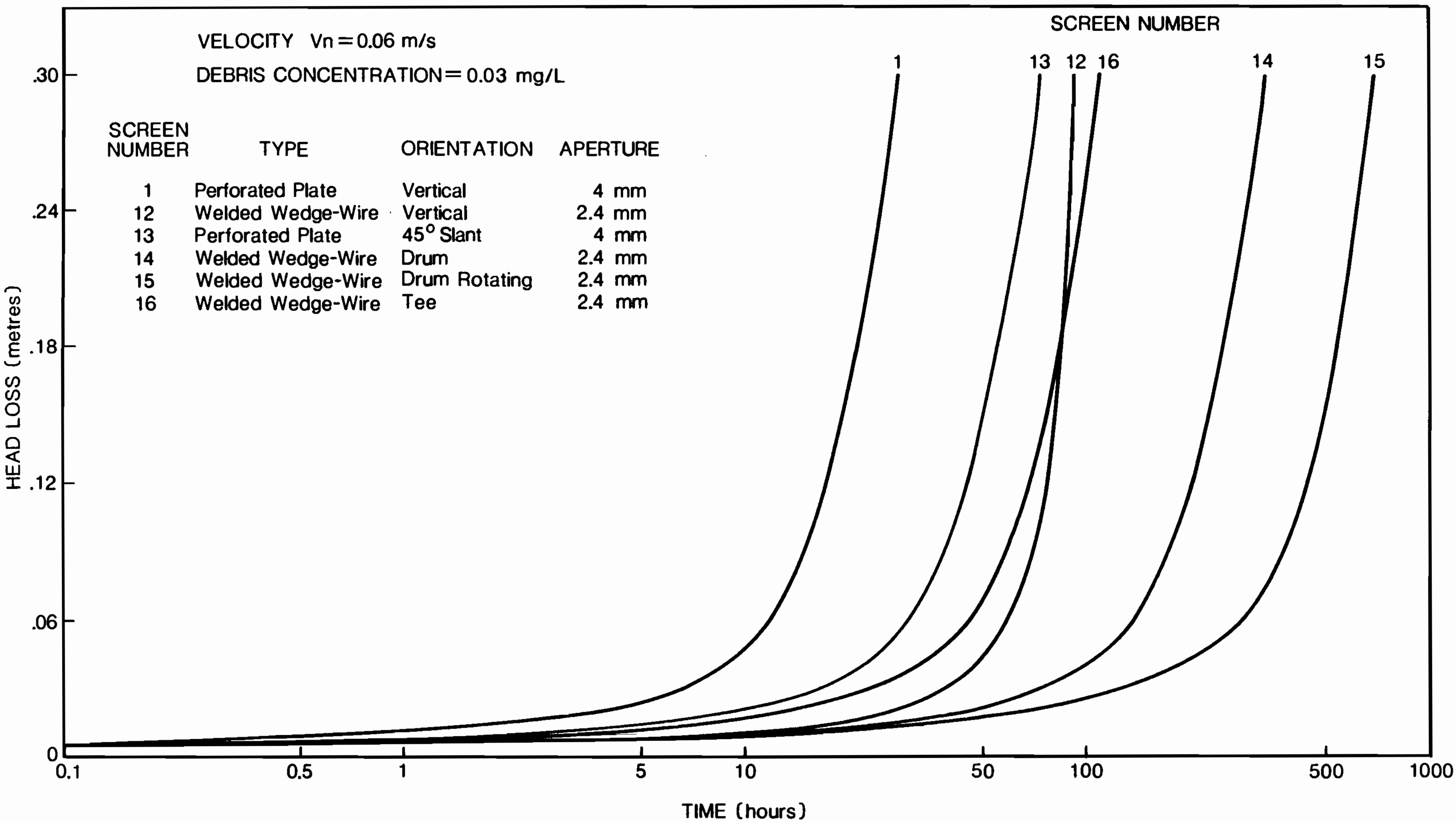


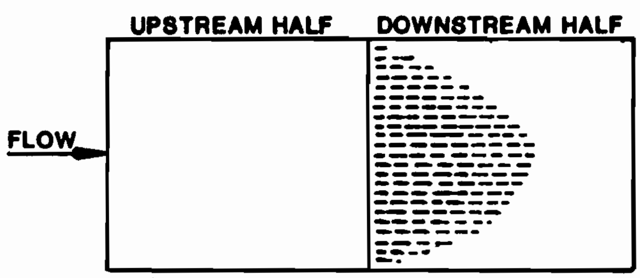
FIGURE 27. Clogging Rates of Various Screen Orientations and Configurations (from Smith, 1982)

The two preceding figures were for debris concentrations of 0.03 mg/1 (0.03 ppm), a value for controlled flow conditions during summer and fall months. Five percent of the time debris concentration may exceed 0.5 mg/1 (0.5 ppm), and occasionally exceed 1 mg/1 (1 ppm). Figures 28 and 29 contain regression plots of headloss against time for debris concentrations ranging from 0.001 to 1.0 mg/1 (0.001 to 1.0 ppm) for the perforated plate and wedge wire, respectively. The approach velocity in both cases is 6.1 cm/s (0.2 ft/s). Looking first at the perforated plate, it took about 2 h to develop 30.5 cm (1 ft) of headloss across the screen. With wedge wire at the same debris level, it required more than 5 h. Concentrations that may occur at extremely high flows, 2266 m^3/s (over 80,000 cfs), especially during the early parts of storm events, may cause debris loads such that acceptable levels of headloss are exceeded in a matter of a few minutes. During such relatively rare occurrences, it may be necessary to reduce diversions for a brief period. During the last 6 years through 1981, the daily mean Sacramento River flow at Sacramento exceeded 2266 m^3/s (80,000 ft^3/s) for a total of only 19 days.

The screen clogging test results can be characterized as encouraging. There are several gaps in the data, especially for screens other than perforated plate, and the tests were conducted in rather small facilities; however, the data do demonstrate that screens with small openings do not become plugged immediately upon being submerged in the Sacramento River. During most of the year, the interval between required cleanings will be on the order of several h, not min. as originally feared. Based on clogging data alone, the wedge wire screens would be most suitable for use in the Sacramento River system.

An attempt was made to determine the movement of debris on the screen as it was being brush cleaned. Due to the turbidity of the water, it was not possible to directly observe during cleaning.

The downstream half of a dirty screen was brushed under water and inspected, then the upstream half was brushed. Sketches were drawn by the observer of the debris pattern left on the screen. Some debris did move onto the downstream half after cleaning the upstream half. The higher the initial headloss, the more debris was moved to the downstream half. This movement tended to concentrate in the pattern shown below:



The debris that was held on the screen did not appear to equal that which was originally on the upstream half, suggesting that some material was lost during cleaning. To answer the question of where the rest of the debris

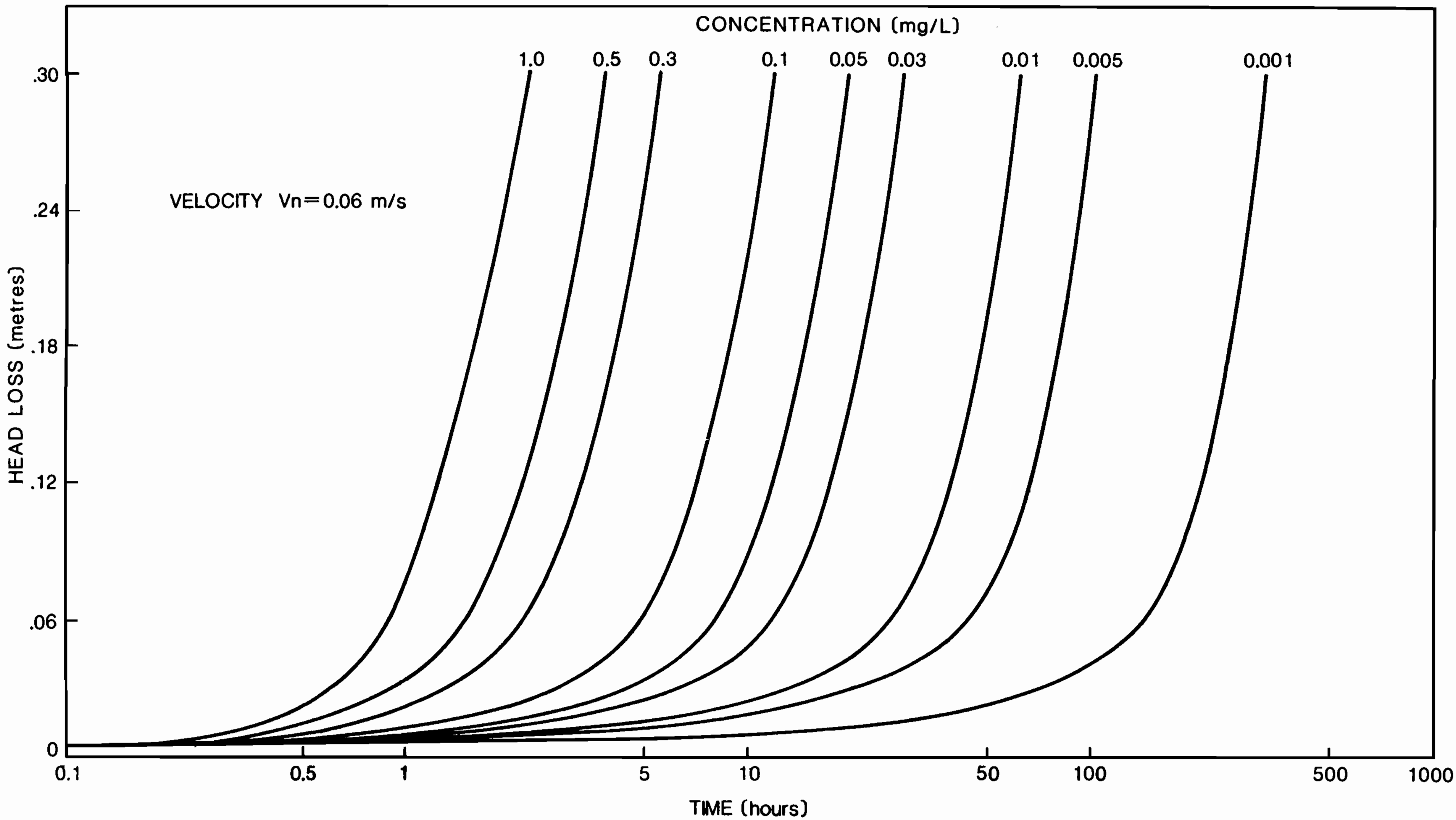


FIGURE 28. Clogging Rates of 4 mm Perforated Plate at Various Debris Concentrations (from Smith, 1982)

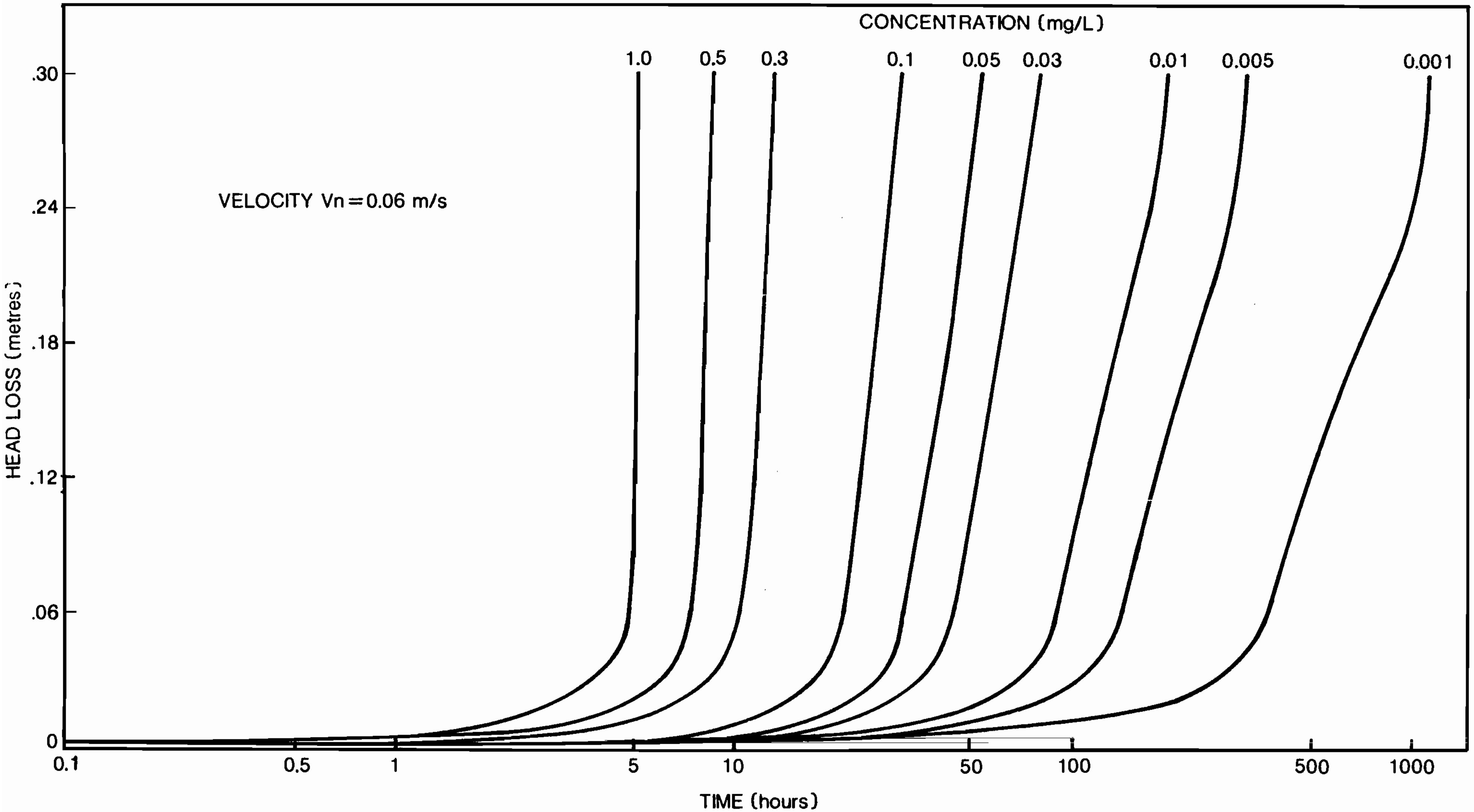


FIGURE 29. Clogging Rates of 2.4 mm Welded-Wire at Various Debris Concentrations (from Smith, 1982)

went, through the screen or into the bypass, three fine mesh screens were made to collect debris during cleaning. One was mounted behind the upstream half, one behind the downstream half, and one at the end of the screen, across the bypass. The amount of debris collected on each screen was weighed after cleaning the downstream half and again after cleaning the upstream half. Results were quite variable, most of the debris collected came from either the screen half being cleaned or the bypass. The amount collected from either varied from 2% to 90%. Unfortunately, the test velocities were not recorded as they certainly would have some effect. The position of the brush assembly may also have had some effect on the direction of movement of the debris.

Data on screen trap efficiency of 3.96 mm (5/32 in.) perforated plate presented by Smith and Ferguson (1979) indicates that 50% or more of the debris in the water will go through the screen when the headloss is less than 0.3 m (1 ft). The percent passing is probably even higher for welded wedge-wire screen. If this holds true along the total length of screen then, as the debris is brushed off the screen, some will go through and the remainder will be resuspended in the flow. Upon contacting the screen again, 50% or more of this debris will go through the screen. This process will result in a doubling of the debris load at the downstream end of the screen. As the brush sweeps off the end there will be a plume of debris of high concentration but short duration that will move into the bypass.

Screen Cleaning - Although considerable effort was directed towards the task of evaluating screen cleaning systems, the data do not readily lend themselves to quantitative treatment. The following discussion handles cleaning in a qualitative manner:

Brushing the screen on one side, under water, cleaned screens that were clogged, i.e. screens that had accumulated enough debris so that the headloss was on the order of 0.3 m (1 ft) or more. A gelatinous film did build up on the backside; however, this film did not affect water flow through the screen. One cleaning problem encountered was when leaves were present in the fall. The leaves tended to roll up in a ball but were eventually swept away. The data on the optimum bristle size and type indicated that brushes with longer and smaller diameter bristles were most effective at removing accumulated debris.

The spray bar system worked well when the screens were cleaned out of water but was much less effective when used underwater. The lack of effectiveness underwater was probably caused by physical limitations in our test apparatus which resulted in only portions of the screen being cleaned.

In summary, the cleaning studies demonstrated that it is technically feasible to keep small (1.3 x 3.1 m [4 x 10 ft]) screens clean when they are suspended in the Sacramento River and experience ambient loads of suspended materials. Because so many variables were being tested, time was not available to test one screen at one set of conditions throughout a complete winter with the object of maintaining acceptable headloss by routine cleaning. The cleaning information derived during this study is presently being extrapolated to a facility of the size envisioned for the Peripheral Canal. The next step in the process should be a large scale test of cleaning device and some conceptual design work on how one can mechanically achieve the required movement of brushes across the screen face. Lifting the screens and cleaning by high pressure water jets will keep the screens clean; however, operations studies are needed to determine if time permits use of this screen cleaning technique for the fish protection facility. Finally, no matter what cleaning method is selected, there may be times during very high flows when it may not be possible to keep the screens clean, and at the same time meet the design flows. Curtailment of diversions will be necessary to protect both the screen structure and fishery resources.

Corrosion Studies - The corrosion studies can be summarized by referring to Figure 30. Stainless steel Type 304 perforated plate and welded wedge-wire did not loose any material over the 4 years of operation and would be suitable for use in Peripheral Canal fish screens (Table 5). Selection of screen material will be based on initial cost as well as anticipated operation and maintenance costs.

SYNTHESIS OF FINDINGS

The results of the biological and engineering research and development programs have led to a series of preliminary design criteria which are reproduced here. An earlier version was circulated to all program participants as a working justification paper on May 29, 1981 (FFTCC 1981c).

Preliminary Design Criteria

The preliminary design criteria are arranged from upstream to downstream and reflect the selection of an "off-river" intake concept as described in our first "working justification paper" (FFTCC 1979a). The criteria are subject to modification due to additional study results and design considerations.

A. Intake

The fish facility would be located in an "off-river" channel, on the left (east) bank of the Sacramento River near the town of Hood, California. The specific location of the turnout, on the outside of a bend, is being studied by mathematical and hydraulic model studies to determine a location where a smooth hydraulic flow through the intake structure can be maintained while minimizing the entrainment of sediment (Hartman et al. 1979).

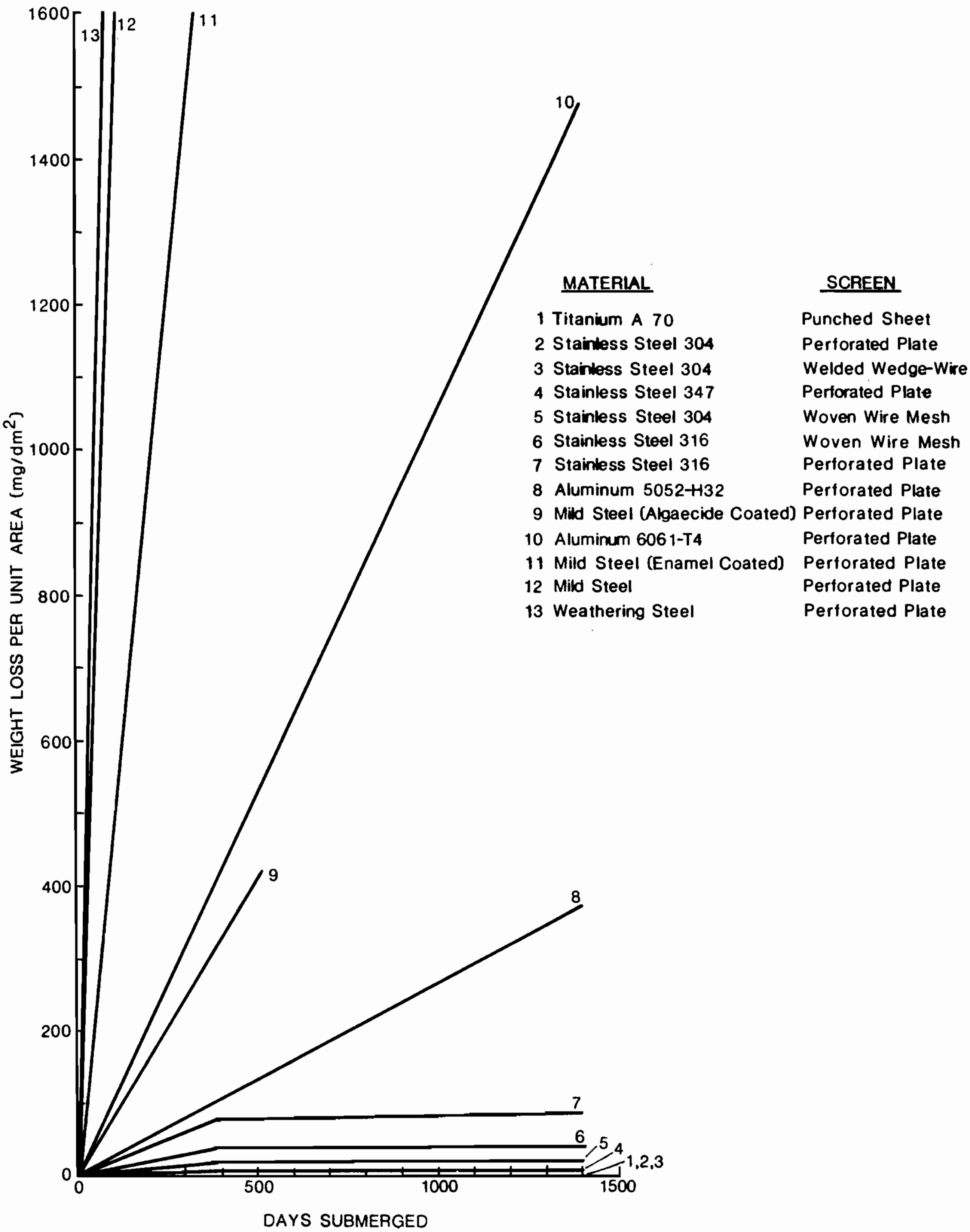


FIGURE 30 CORROSION RATE OF POTENTIAL FISH SCREEN MATERIALS (FROM SMITH, 1982)

TABLE 5. Corrosion of possible fish screen materials (from Smith, 1982)

Material	Screen	Percent Weight Loss per 1000 Days: All Samples	Samples With Fasteners	Samples Without Fasteners	Samples Washed	Sampled Not Washed
Titanium A 70	Punched Sheet	0.00	- -	0.00	0.00	- -
Stainless Steel 304	Perforated Plate	0.00	0.00	0.00	0.00	0.00
Stainless Steel 304	Welded Wedge-Wire	0.00	- -	- -	0.00	0.00
Stainless Steel 347	Perforated Plate	0.02	0.00	0.04	0.02	0.02
Stainless Steel 304	Woven Wire Mesh	0.04	0.04	0.05	0.05	0.04
Stainless Steel 304/202	Welded Wedge-Wire	0.05	- -	- -	0.05	- -
Stainless Steel 316	Woven Wire Mesh	0.09	0.07	0.11	0.12	0.09
Stainless Steel 316	Perforated Plate	0.20	0.19	- -	0.24	0.17
Aluminum 5052-H32 (Sealed)	Perforated Plate	2.23	- -	2.23	- -	2.23
Aluminum 5052-H32	Perforated Plate	2.28	2.39	2.17	3.49	1.88
Mild Steel (Algaecide Coated)	Woven Wire Mesh	2.86	- -	2.86	2.86	- -
Aluminum 6061-T4 (Sealed)	Perforated Plate	4.60	- -	4.60	- -	4.60
Aluminum 6061-T4	Perforated Plate	9.33	8.92	9.75	8.76	9.53
Mild Steel (Enamel Coated)	Perforated Plate	10.82	- -	10.82	11.24	10.68
Mild Steel	Perforated Plate	1/				
Weathering Steel	Perforated Plate	1/				

1/ Samples were lost because of disintegration.

B. Trashrack

1. Velocity through the trashrack may range between 0.61 and 0.91 m/s (2 and 3 ft/s) and the facility will be designed to minimize variations in velocity across the face of the structure. This criterion is based on the results of studies just completed which indicate the velocities of at least 0.61 m/s (2 ft/s) are necessary to assure the passage of juvenile fish without delay (Reading 1982b).

2. Trashrack bar spacing will be no less than 22.9 cm (9 in.) between bars. This criterion is also based on the results of studies just completed (Reading 1982b) as well as work performed by Hanson and Li (MS) with juvenile chinook salmon. The objective is to pass juvenile fish without delay and allow migrating adults to pass through the structure.

3. The trashrack will be located as near to the river as possible at a point where flow is most uniform. The objective is to minimize hydraulic problems associated with the structure.

4. Each trashrack bar will be oriented with its long side parallel to the diversion flow. The purpose of this criterion is to assure the passage of fish by minimizing the turbulence associated with the trashrack, and reduce the habitat for predators.

5. During times of high river flows, large mats of tangled debris and logs have been observed floating down river. These mats will be stopped by the trashrack and a system would be needed to warn the operators of increasing loading on the trashrack. Trashrack rakes would be used to remove the debris and logs.

6. There will be a sill on the bank of the river of at least 3 m (10 ft) to minimize the entrainment of benthic organisms and bedload material. This should provide some measure of protection from entrainment for benthic fish which are migrating past the intake structure, although we have been unable to quantify the value of such a structure to fish.

C. Approach Channel

1. The channel will be designed to minimize deadwater areas, turbulence, and eddies. These hydraulic flow disturbances have been identified in other facilities as locations where predatory fish accumulate to prey on juvenile outmigrant fish (FFTCC 1980b).

2. Each side and the floor of the channel may taper at no more than a 10^{o} angle from a plane parallel to the centerline of the channel. Studies conducted by Meinz (1978a)

and Mecum (1980) indicated that this angle was critical to the successful passage of juvenile fish, with an angle of 10° producing the highest gain in fish passage while still allowing the channel to taper.

3. The channel velocity will not be less than twice the approach velocity to the screen and must not exceed 0.91 m/s (3 ft/s). This criterion is based on the need to provide a positive downstream flow component to guide the fish past the screen. Small fish detect velocity gradients and orient themselves to migrate downstream. The maximum velocity of 0.91 m/s (3 ft/s) was selected to avoid scouring the unlined "off-river" channel.

D. Screen Structure

1. Design approach velocity will be 6.1 cm/s (0.2 ft/s) perpendicular to the screen face and uniform across the wetted face of the screen. Variations during operation of 3 cm/s (0.1 ft/s) in spots would be acceptable. This criterion is based on the results of a long series of swimming performance studies (Sasaki et al. 1972; Fisher 1976, 1981). This criterion is designed to protect the most sensitive stage of juvenile American shad in darkness, and is based on the results of tests reported by Kano (1982). This criterion will also protect juvenile salmon.

2. The screen will be vertically oriented.

3. The channel sides and floor may taper at no more than a 10° angle from a plane parallel to the centerline of the channel. The rationale is presented in C.2.

E. Screen Material

1. The percent open area will not be less than 46%. The materials tested in our retention, swimming ability, clogging, and cleaning tests had open areas of at least this value. Thus, no test data are available for materials with less open area.

2. Perforated plate material will have holes which do not exceed a diameter of 3.96 mm (5/32 in.). This criterion is based on the results reported by Fisher (1978). The criterion will protect all chinook salmon and American shad juveniles passing the Hood intake site. Sturgeon 26 mm (1.0 in.) or longer should also be protected by this material (Reading 1982a).

3. Slotted material will meet the following criteria:

   a. Continuous slot material will not exceed a 2.4 mm (3/32 in.) slot width.

b. Rectangular slot material will have a slot width of 2.4 mm (3/32 in.) if the diagonal opening of the material exceeds 3.96 mm (5/32 in.).

These criteria are based on studies similar to those for perforated plate conducted with the continuous slot material, and will protect all chinook salmon and American shad juveniles passing the Hood intake site (Kano MSa). This material will also protect sturgeon which have reached 27 mm (1.1 in.) in length (Reading 1982a).

4. Clogging tests have shown the perforated plate to clog much faster than slotted material, and would therefore require more frequent cleaning (Smith and Ferguson 1979). Selection of the material must await the results of the tests with a new long term facility with slotted material, and a detailed analysis of capital and OM&R costs.

F. Bypass

1. The bypass will be an open channel with depth maximized within the constraint that the channel must be at least 0.91 m (36 in.) wide. The vertical displacement of fish will be minimized. This criterion is based on the results of the work reported by Mecum (1980) which showed that maximum passage of juvenile American shad and chinook salmon required a bypass width of at least 0.91 m (36 in.), and that reported elsewhere (Brett and Alderdice 1958).

2. The velocities will not be less than the channel velocity nor exceed 0.91 m/s (3 ft/s). This criterion was selected to move the fish through the system as quickly as possible, while avoiding sudden acceleration or decelerations which could disorient or stress the fish.

3. Each side and the floor may taper at no more than a 10° angle from the plane parallel to the centerline of the channel. The rationale has been discussed in C.2.

4. Turbulence must be minimized. The rationale has been discussed in C.1.

5. The bypass channel will be long enough to eliminate the chance of multiple exposure to the screen system during tidal reversals.

G. Fish Bypass Exit

1. Turbulence at the bypass exit should be minimized. The rationale has been discussed in B.1.

2. Bypass and river velocity must match to the extent possible. This criterion will provide a less turbulent

return to the river. Due to fluctuations in the river flow, an average water velocity may need to be chosen (FFTCC 1981a).

H. Pumps

1. The pumps will be designed to prevent delay, disorientation, and mortality of both juvenile and adult migrants.

2. The pumps will only operate when needed. Pumping would be required to maintain bypass velocities during low river flow periods when tidal effects and head losses in the system combine to create reverse flows.

3. The pump will be located as near to the river return as possible.

I. Miscellaneous

1. A positive downstream flow of at least 28 m^3/s (1,000 ft/s) will be maintained through the bypass system.

2. Instream and overhead structures will be minimized in any channel where fish are present and any instream structures should be streamlined to minimize turbulence and eddies. These conditions are known to create conditions favorable to predation and thus should be minimized (FFTCC 1980b).

Facility Selection

The evaluations of various screening alternatives, field evaluations of existing facilities, and the results of the biological and engineering studies led to the consideration of two fish screen configurations, both located in an "off-river" channel.

The "off-river" location was selected to allow the maintenance of a positive downstream flow component past the fish screen. This positive downstream flow reduces the potential exposure of migrating fish to the screen by providing a flow component to guide fish past the screen. One major study element remains to be completed before the full range of benefits available in this configuration are achieved. Development of the low head pump required to maintain these flows in the "off-river" channel has not been completed. Failure to develop such a pump would result in a situation similar to that expected in the "on-river" scheme, reducing or eliminating the opportunity to move fish past the screen quickly. The decision to adopt an "off-river" configuration would than have to be re-evaluated.

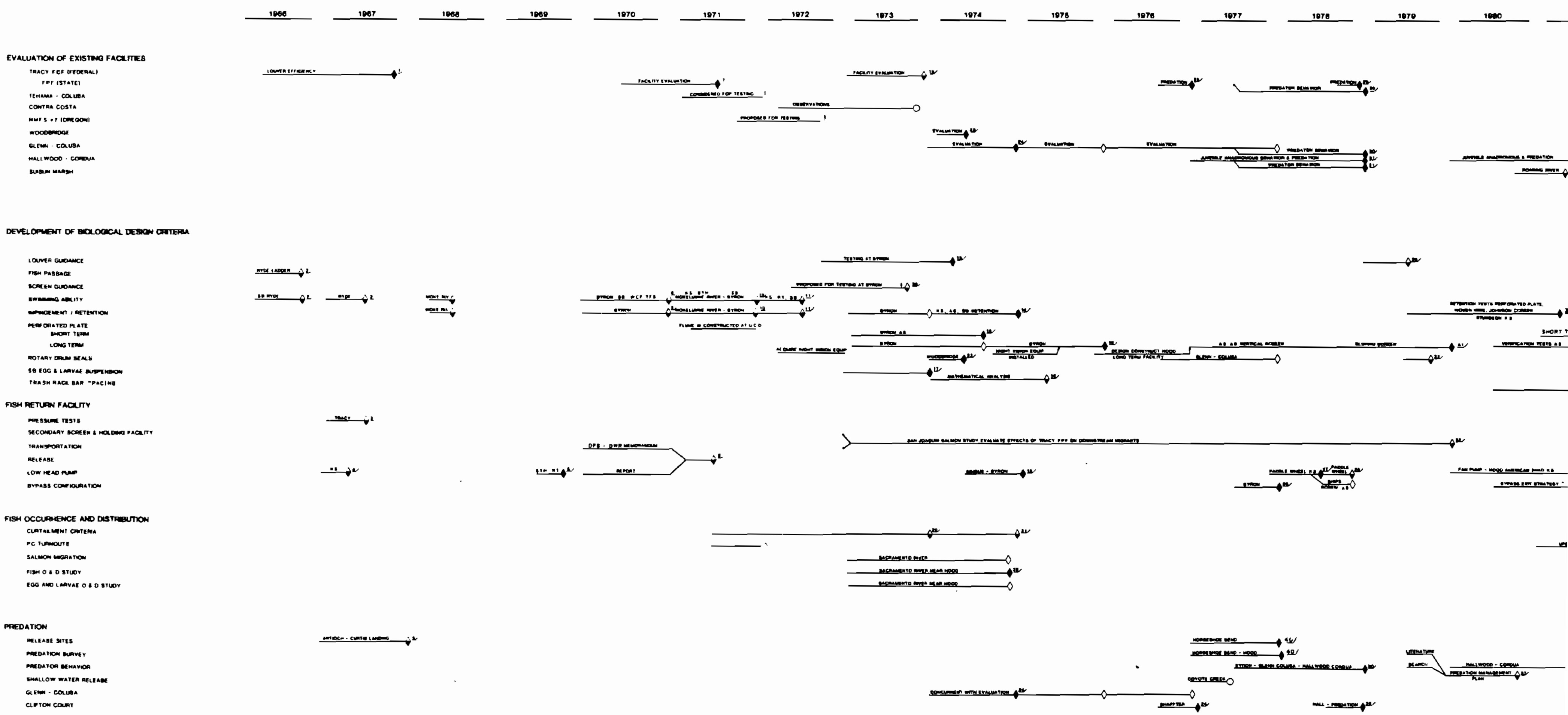
The two screen types selected for detailed analysis were the "plate along one bank" and the "double vee." Small screens constructed by DFG, representative of each configuration, are in existence in California. Both configurations were considered equally until a rationale for a selection was established.

The result of this process was the selection of the "double vee" with a split intake channel (Figures 31 and 32) for the proposed intake. A first stage of such a facility could be constructed, and an example, capable of conveying one quarter of the flow, is presented in Figure 33. This design would consist of the lower portion of one vee. Cross-sections of the facility are shown in Figure 34. A similar facility with a common intake channel was considered and rejected because of the difficulties in meeting the channel velocity criteria, a problem which it shared with the "plate along one bank" screen.

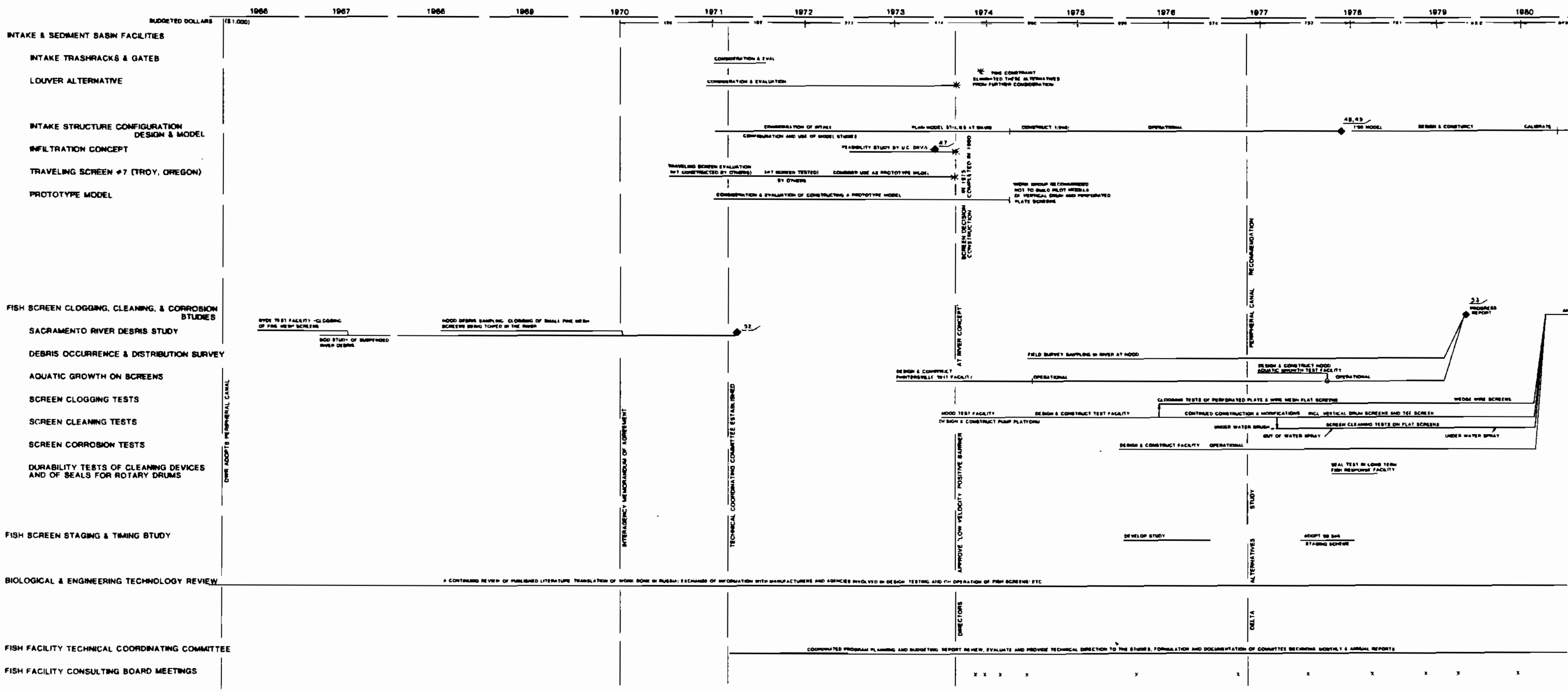
The selection of the "double vee" screen with a split intake channel was a consensus of the Fish Facilities Technical Coordinating Committee, and was endorsed by the Fish Facilities Consulting Board at their April 15, 1982 meeting. These actions were qualified by the need to develop a low head pump to maintain the positive downstream flow in the "off-river" channel.

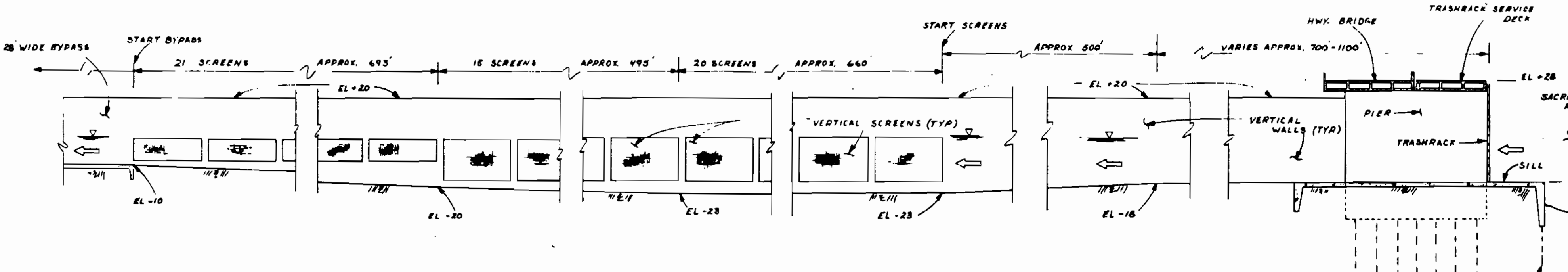
The concept was never officially adopted because of the rejection of Senate Bill 200 by the voters at the June, 1982 election, after which the program was directed to wrap up the studies and phase out all work by December, 1982.

DELTA FISH FACILITIES WORK - BIOLOGICAL STUDIES

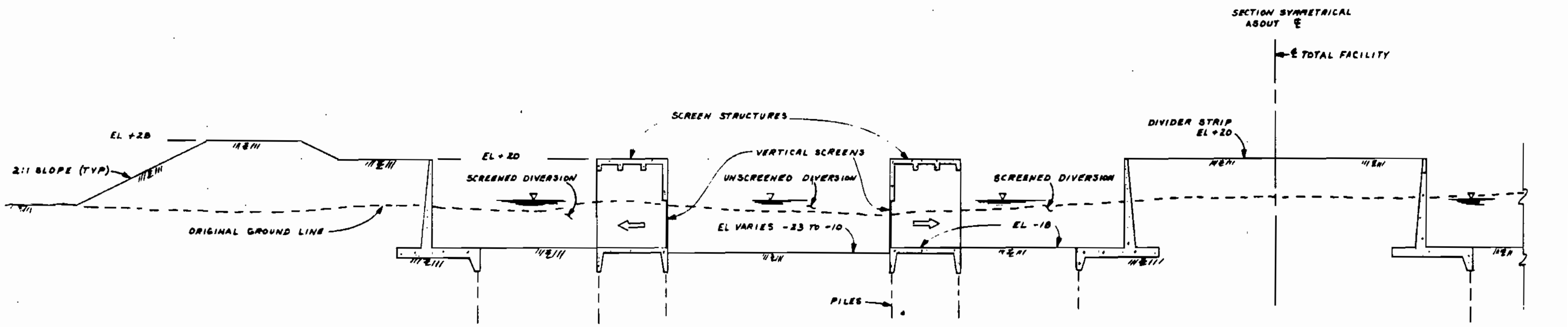


DELTA FISH FACILITIES WORK - ENGINEERING STUDIES AND PROGRAM MANAGEMENT



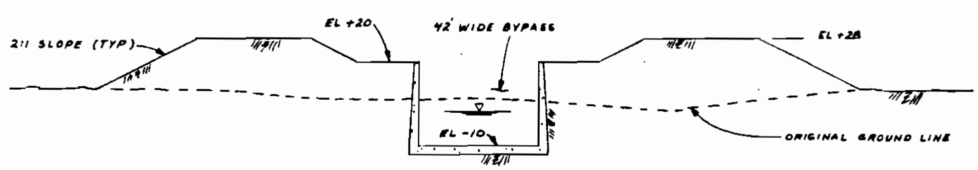


SECTION A-A
SCALE 1" = 20'



SECTION B-B
SCALE 1" = 20'

PRELIMINARY
SUBJECT TO REVISION



SECTION C-C
SCALE 1" = 20'

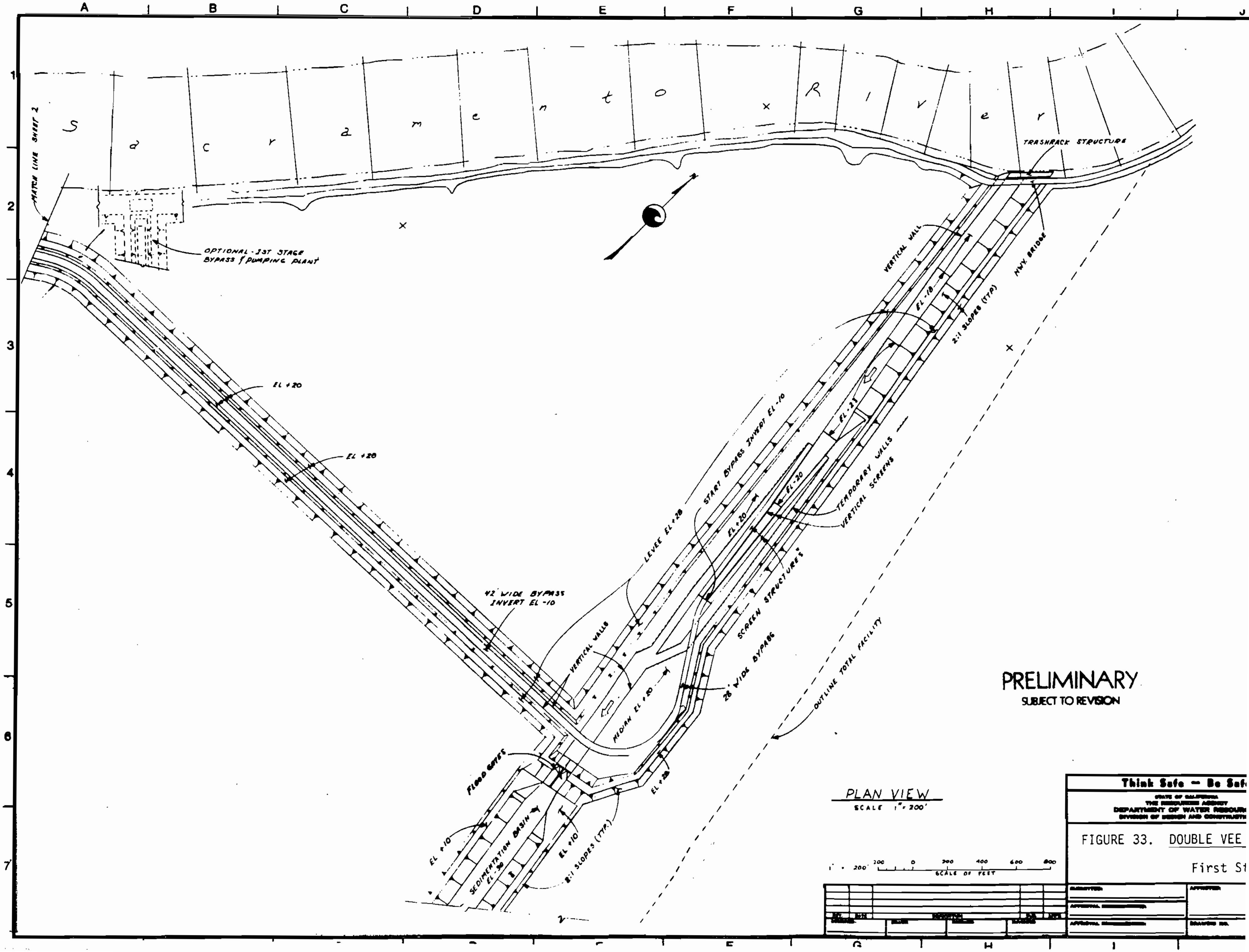
1" = 20'   20 0 20 40 60 80
SCALE OF FEET

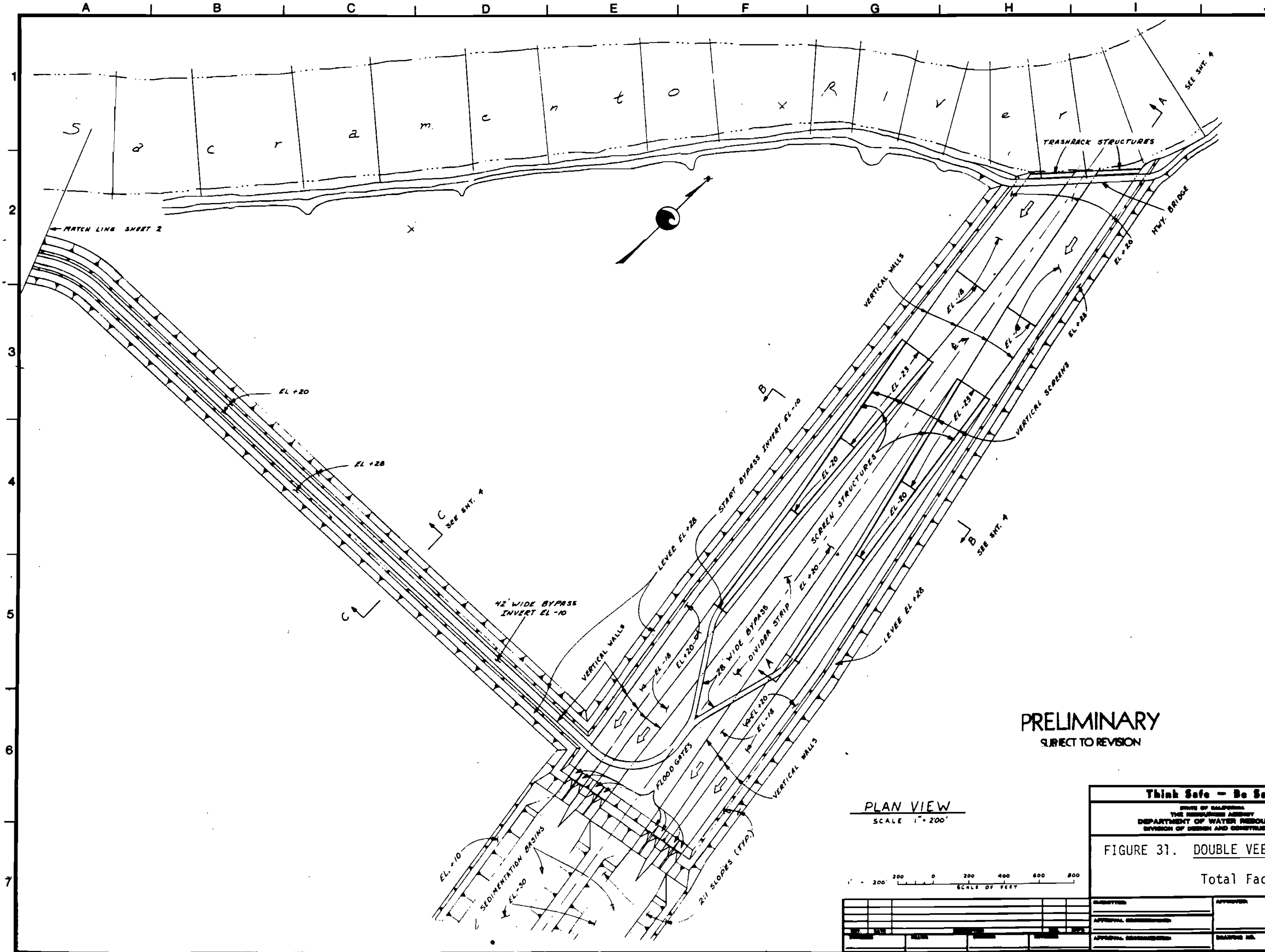
Think Safe — Be Sa

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOU
DIVISION OF DESIGN AND CONSTRUC

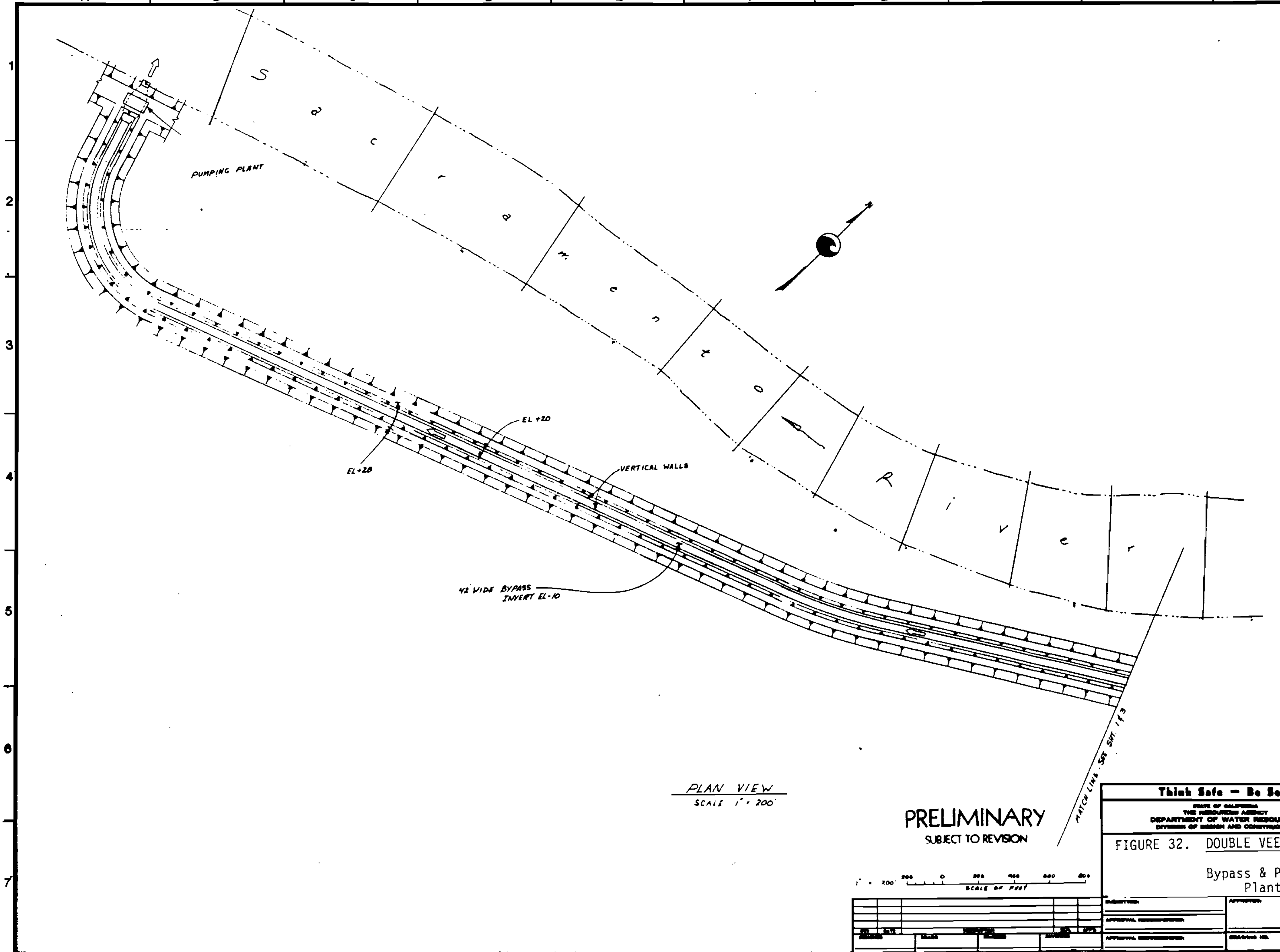
FIGURE 34. DOUBLE VEE

Sectic


Sacramento River
MATCH LINE SHEET 2
OPTIONAL - 1ST STAGE BYPASS & PUMPING PLANT
TRASHRACK STRUCTURE
HWY. BRIDGE
VERTICAL WALL
EL -18
2:1 SLOPES (TYP)
EL +20
EL +28
START BYPASS INVERT EL -10
EL -25
EL -20
TEMPORARY WALLS
VERTICAL SCREENS
LEVEE EL +28
EL +20
SCREEN STRUCTURES
42' WIDE BYPASS INVERT EL -10
VERTICAL WALLS
28' WIDE BYPASS
MEDIAN EL +20
OUTLINE TOTAL FACILITY
FLOOD GATES
EL +28
SEDIMENTATION BASIN
EL -30
EL +10
EL +10
2:1 SLOPES (TYP.)
PLAN VIEW
SCALE 1" = 200'
SCALE OF FEET
PRELIMINARY
SUBJECT TO REVISION
Think Safe — Be Safe
DEPARTMENT OF WATER RESOURCES
FIGURE 33. DOUBLE VEE
First St



Sacramento River
TRASHRACK STRUCTURES
HWY. BRIDGE
SEE SHT. 4
MATCH LINE SHEET 2
EL +20
EL +28
VERTICAL WALLS
VERTICAL SCREENS
EL -18
EL -23
EL -20
START BYPASS INVERT EL -10
SCREEN STRUCTURES
LEVEE EL +28
42' WIDE BYPASS INVERT EL -10
28' WIDE BYPASS
DIVIDER STRIP
FLOOD GATES
SEDIMENTATION BASINS
EL -30
EL -10
2:1 SLOPES (TYP.)
PRELIMINARY
SUBJECT TO REVISION
PLAN VIEW
SCALE 1" = 200'
SCALE OF FEET
Think Safe — Be Sa
DEPARTMENT OF WATER RESOU
FIGURE 31. DOUBLE VEE
Total Fac


S a c r a m e n t o R i v e r
PUMPING PLANT
EL +20
EL +28
VERTICAL WALLS
42' WIDE BYPASS
INVERT EL-10
PLAN VIEW
SCALE 1" = 200'
PRELIMINARY
SUBJECT TO REVISION
SCALE OF FEET
Think Safe — Be Sa
DEPARTMENT OF WATER RESOU
FIGURE 32. DOUBLE VEE
Bypass & P
Plant

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APPENDIX I

DELTA FISH FACILITIES PROGRAM

SUMMARY OF THE BIOLOGICAL

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CONVERSION FACTORS

Quantity	To Convert from Metric Unit	To Customary Unit	Multiply Metric Unit By	To Convert to Metric Unit Multiply Customary Unit By
Length	millimetres (mm)	inches (in)	0.03937	25.4
	centimetres (cm) for snow depth	inches (in)	0.3937	2.54
	metres (m)	feet (ft)	3.2808	0.3048
	kilometres (km)	miles (mi)	0.62139	1.6093
Area	square millimetres (mm^2)	square inches (in^2)	0.00155	645.16
	square metres (m^2)	square feet (ft^2)	10.764	0.092903
	hectares (ha)	acres (ac)	2.4710	0.40469
	square kilometres (km^2)	square miles (mi^2)	0.3861	2.590
Volume	litres (L)	gallons (gal)	0.26417	3.7854
	megalitres	million gallons (10^6 gal)	0.26417	3.7854
	cubic metres (m^3)	cubic feet (ft^3)	35.315	0.028317
	cubic metres (m^3)	cubic yards (yd^3)	1.308	0.76455
	cubic dekametres (dam^3)	acre-feet (ac-ft)	0.8107	1.2335
Flow	cubic metres per second (m^3/s)	cubic feet per second (ft^3/s)	35.315	0.028317
	litres per minute (L/min)	gallons per minute (gal/min)	0.26417	3.7854
	litres per day (L/day)	gallons per day (gal/day)	0.26417	3.7854
	megalitres per day (ML/day)	million gallons per day (mgd)	0.26417	3.7854
	cubic dekametres per day (dam^3/day)	acre-feet per day (ac-ft/day)	0.8107	1.2335
Mass	kilograms (kg)	pounds (lb)	2.2046	0.45359
	megagrams (Mg)	tons (short, 2,000 lb)	1.1023	0.90718
Velocity	metres per second (m/s)	feet per second (ft/s)	3.2808	0.3048
Power	kilowatts (kW)	horsepower (hp)	1.3405	0.746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0.14505	6.8948
	kilopascals (kPa)	feet head of water	0.33456	2.989
Specific Capacity	litres per minute per metre drawdown	gallons per minute per foot drawdown	0.08052	12.419
Concentration	milligrams per litre (mg/L)	parts per million (ppm)	1.0	1.0
Electrical Conductivity	microsiemens per centimetre (uS/cm)	micromhos per centimetre	1.0	1.0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(1.8 × °C)+32	(°F−32)/1.8